NOTES IN MECHANICAL ENGINEERING.

620.

NOTES

IN

MECHANICAL ENGINEERING.

COMPILED PRINCIPALLY FOR

THE USE OF STUDENTS ATTENDING THE LECTURES

IN THIS SUBJECT

AT THE CITY OF LONDON COLLEGE.

M. E. Cooley,

BY

HENRY ADAMS,

MEMB. INST. MECHANICAL ENGINEERS, MEMB. INST. CIVIL ENGINEERS,
MEMB. SOCIETY OF ENGINEERS, ETC.

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PREFACE.

"The City and Guilds of London Institute for the Advancement of Technical Education" having, in the year 1880, issued a programme of instruction in various subjects, upon the basis of the system so well developed by the Government Department of Science and Art, the author became enrolled as a teacher of Mechanical Engineering in connection with the Institute, and delivered a series of lectures in that subject at the City of London College. His efforts to render the course attractive and useful were fairly successful, as he was able to draw upon a very large collection of diagrams prepared for machine construction and other allied science subjects; and these, supplying the ground work of the illustrations, enabled him to devote some time to the preparation of others specially applicable to the circumstances of the case. However, the very abundance of the information proved in itself a drawback, as the majority of the students, coming totally unprepared by previous training for taking notes, and having but little aptitude for dealing with formulæ, or even for the classification of facts, were unable to assimilate the technical food placed before them. The first course of thirty lectures was illustrated by one hundred and fifty-five diagrams besides blackboard sketches, and yet embraced only the first four lines of the syllabus issued by the Committee, while so far from being exhaustive of that

portion of the subject, the author felt that he had merely been able to direct attention to some of the more important facts and principles.

If students would give the matter a little consideration, it would be apparent to them that the teacher's work must of necessity be supplemented by a large amount of home work on their part. If they could only be sufficiently impressed with the fact that science cannot be *absorbed*, but must be *learnt*, the labour of *teaching* would be considerably lightened.

The present work may be described as an effort to write out a part of the student's notes for him, in the hope that he will thereby be enabled to give a more undivided attention to the illustrations and descriptions of mechanical details and operations put before him in the lectures. It is not intended in any way to supersede the ordinary text-books, but simply to supplement them in the form of a student's own notes, which should represent a summary of his reading and study. The notes are compiled from various sources; in many cases the authority is given, in others the information is original or has been derived from sources of which no record has been kept. Although the text has been carefully read through, there are doubtless some errors which have escaped notice, and which the author will be glad to have pointed out. He will also be grateful for any suggestions from students or others with regard to increasing the efficiency of this as a STUDENT'S NOTE BOOK.

60, QUEEN VICTORIA STREET, E.C.
1*st October*, 1883.

CONTENTS.*

PART I.—SECTION I.

SECTION II.

SECTION III.

SECTION IV.

SECTION V.

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* Although the classification adopted by the Committee, as given in the published syllabus of the Mechanical Engineering Examination, is open to objection, it has been thought better, in the present interest of students preparing for that examination, to retain this syllabus intact. It has therefore been divided into sections, and condensed information, consisting of facts and formulæ, is placed under each head. Further particulars are given upon the illustrative diagrams, especially in Parts II. to VI.

SECTION VI.

INDEX TO SUBJECTS.

PART I.—SECTION III.

PART I.—SECTION IV.

PART I.—SECTION V.

PART I.—SECTION VI.

PART II.

PART III.

PART IV.

PART V.

PART VI.

NOTES

IN

MECHANICAL ENGINEERING.

PART I.—SECTION I.

FUNDAMENTAL PRINCIPLES OF MECHANICS.

1. Force and Matter.

Motion is change of place.

Force is that which produces or destroys motion, or which tends to produce or destroy it.

Matter is that which is the subject of motion or a tendency to motion.

Forces in equilibrium are called pressures or reactions.

Gravity is the attraction one body has for another, and, being proportional to the mass of the body, the attraction of the earth practically overwhelms all others. The direction of attraction is towards the centre of the mass, hence under the action of gravity all bodies tend to fall towards the centre of the earth.

Centre of Gravity is that point in a body through which the resultant of the gravities of its parts passes, in every position the body can assume.

B

Accelerating Force of Gravity is the velocity imparted to bodies falling near the surface of the earth, in lat. 45° = 32·169545 ft. per sec., say $32 \cdot 2 = g$.

2. Mass and Weight.

Density is the quantity of matter in a unit of volume.

Mass is the quantity of matter in a body of any volume, = density × magnitude $\left(\text{also } M = \frac{W}{g}\right)$.

Weight is the mass × force of gravity, which is only constant for one place, $\therefore W \propto M\, g$.

Work = weight × space passed through vertically, or pressure exerted × space passed through in any direction.

Momentum = mass × velocity.

Moving Force, or the moving quantity of a force, is the additional momentum which it communicates in each second to a body.

3. Work and Energy.

A unit of work is the power expended when a pressure of 1 lb. is exerted through a space of 1 foot.

A foot-pound is the measure of one unit of work.

A horse-power is the exertion of 33,000 units of work or foot-lbs. in the period of 1 minute.

Energy in mechanics means capacity for performing work, and is measured in foot-lbs.

Potential energy is the product of the effort into the distance through which it is capable of acting.

Actual energy, kinetic energy, or accumulated work of a moving body is the product of the mass of the body into half the square of its velocity, or the weight of the body into the height from which it must fall to acquire its actual velocity = $\left(\frac{m\, v^2}{2} = \frac{W\, v^2}{2\, g}\right)$.

Vis viva of a moving body is the product of the mass of the body into the square of its velocity, or double the actual energy $\left(m\,v^2 = \dfrac{W\,v^2}{g}\right)$.

4. Inertia and Momentum.

Inertia is resistance to communication of motion.

Momentum is resistance to extinction of motion.

They are equal to each other, and of opposite character.

They are compared with *Work* by ascertaining h necessary to create the v under action of g, and considering W as moved through h, giving result in foot-lbs. $= \dfrac{W\,v^2}{2\,g}$.

In calculating the power exerted in moving a load, as a truck on a railway, we have the inertia overcome in reaching the velocity attained $\left(\dfrac{W\,v^2}{2\,g}\right)$ added to the work done transporting the load through the space passed over ($W\,\mu\,s$).

In coming to rest the inertia is given up again as momentum. The value of the momentum is irrespective of the distance in which the velocity was acquired; its effect depends entirely upon the distance in which it is expended.

5. Equilibrium.

May be stable, unstable, indifferent, or mixed.

When a body is resting on another, in such a position that its centre of gravity is the lowest possible, it is in stable equilibrum: e. g. when vertically under the point upon which it is supported. When the highest possible, it is in unstable equilibrium: e.g. when vertically over point of support. When constant for any position, the equilibrium is indifferent: e. g. a sphere. When stable with regard to movement in one direction, and unstable or indifferent with regard to another direction, it is said to be in a position of mixed equilibrium : e. g. a cylinder lying on its side.

6. Units employed in Engineering Calculations.

Dimensions in inches.

Loads or forces in lbs.

Stresses in lbs. per square inch.

Fluid pressure in lbs. per square inch.

Velocities and accelerations in feet per second.

Mechanical work in foot-lbs.

Speeds of rotation in revolutions per minute, or in angular velocity per second.

Statical moments (as bending and twisting moments) in inch-lbs.—*Unwin's Machine Design.*

7. French Measures.

1 Metre or 1 m. = $3' \, 3\frac{3}{8}''$

1 Decimetre or 1 dm. (very seldom used) = $3\frac{15}{16}''$ or nearly 4 inches.

1 Centimetre or 1 cm. or 1 c/m. = $\frac{3}{8} \, \frac{1}{64}''$ or say $\frac{3}{8}''$ full.

1 Millimetre or 1 mm. or 1 m/m. = $\frac{3}{64}''$ or about $\frac{1}{20}$th of an inch.

Millimetres per metre $\times \cdot 012$ = inches to 1 foot.

PART I.—SECTION II.

THE PROPERTIES OF MATERIALS USED IN MECHANICAL ENGINEERING, WROUGHT IRON, STEEL, CAST IRON, BRASS, WOOD, ETC.

8. Varieties of Iron.

Wrought Iron.—Fibrous—Tough—Soft—Ductile at high temperatures, but not fluid—Welded at 1500° or 1600° F.—Easily oxidised—Forged, hammered, or rolled to various shapes—Contains very little carbon.

Steel.—Fibrous to granular—Containing small amount of

carbon may be welded, and with more carbon may be cast—Can be forged—Very tough and strong—May be tempered—Special properties due to some extent to silicon—Used chiefly for tools.

Cast Iron.—Crystalline—Brittle—Fluid at high temperatures—Takes complicated shapes by casting in a mould—Contains much carbon—The various qualities known as Nos. 1, 2, and 3.

Colours to represent them upon drawings:—

Wrought iron	Blue (Prussian blue).
Steel	Purple (Violet carmine).
Cast iron	Grey (Payne's grey).

9. Effect of Carbon in Iron.

No.	Name.	Percentage of Carbon.	Properties.
1	Malleable iron	0·25	Is not sensibly hardened by sudden cooling.
2	Steely iron ..	0·35	Can be slightly hardened by quenching.
3	Steel	0·50	Gives sparks with a flint when hardened.
4	„	1·00 to 1·50	Limits for steel of maximum hardness and tenacity.
5	„	1·75	Superior limit of welding steel.
6	„	1·80	Very hard cast steel, forging with great difficulty.
7	„	1·90	Not malleable hot.
8	Cast iron ..	2·00	Lower limits of cast iron, cannot be hammered.
9	„	6·00	Highest carburetted compound obtainable.

—*Bauerman.*

10. Common Ores of Iron.

Magnetic Oxide.
Red Hæmatite.
Brown Hæmatite.

Spathose iron ore, or iron glance.
Clay Ironstone.
Black Band Ironstone.

11. Pig-Iron.

Hot-blast and Cold-blast.—Named from the temperature of the blast used in smelting the ores. Hot-blast generally quicker and more economical, but the metal is not considered to be so strong. Difficult to distinguish the two varieties, but, other circumstances being equal, hot-blast iron has rather a finer grain, duller fracture, with sometimes patches of coarse grains, and usually more impurities. Increasing the blast or reducing the supply of fuel makes the iron whiter, harder, and less suitable for re-melting, but better for conversion into wrought iron or steel.

12. Classification of Pig-Iron.

Bessemer Iron.—A variety of pig-iron made from hæmatite ores for conversion into steel, very free from impurities.

Foundry Iron.—All pig-iron having grey fracture and large proportion of uncombined carbon, produced under high temperature and full supply of fuel.

Forge Iron.—White pig-iron, almost free from uncombined carbon, suitable for conversion into wrought iron, produced with low temperature or insufficient fuel, frequently run from blast furnace into iron moulds, rendering it brittle for ease in breaking up.

13. Refining

Is a combination of chemical and mechanical processes by which pig-iron is deprived of its impurities previously to its conversion into wrought iron.

Refining consists simply of melting the pig-iron with coke

or charcoal in an open hearth or "refinery furnace," supplied with an air blast so as to impinge on the melted metal and furnish an oxidising atmosphere. This carries off a portion of the carbon, and at the same time removes a portion of the impurities, particularly silicon, in the shape of slag. The melted metal, having lost some of its carbon, is then poured into a cast-iron trough kept cold by water, and the sudden chilling has the effect of converting soft grey iron into hard silvery-white metal, the carbon which formerly existed in the shape of graphite entering into perfect chemical combination. By this change the fluidity of the iron is reduced, and the subsequent puddling process facilitated.

The loss of weight in refining crude iron averages 10 per cent., and the weekly production of a refinery furnace is from 80 to 160 tons.

14. Puddling

Is the process of obtaining wrought iron by burning the carbon out of cast iron. The oxygen of the air, at the high temperature employed, combines with the carbon to form carbonic oxide gas, which escapes. In hand-puddling the mass is stirred about until it is of sufficient tenacity to be lifted out of the furnace; in Danks' rotary furnace the revolution of the furnace effects the same as the hand labour.

If the operation be stopped before the carbon is all removed, puddled steel is obtained.

15. Qualities of Wrought Iron.

(*a*) Iron easily worked hot, and hard and strong when cold, used for rails.

(*b*) Common iron, used for ships, bridges, and sometimes for shafting.

(*c*) Single, double, and treble best iron, from Staffordshire and other parts where similar qualities are made. The single

or double best is used for boilers. Double and treble best are used for forging.

(*d*) Yorkshire iron, from Lowmoor, Bowling, or other forges where only fine qualities are made. The best Yorkshire iron is very reliable, and uniform in quality. It is used for tyres, for difficult forgings, for furnace plates exposed to great heat, for boiler plates which require flanging, &c.

(*e*) Charcoal iron, very ductile and of best quality.

—*Unwin's Machine Design.*

16. Defects in Wrought Iron.

Cold-shortness is produced by the presence of a small quantity of phosphorus as an impurity. The iron is brittle when cold, but of ordinary character when heated. It cracks if bent cold, but may be forged and welded at high temperatures.

Red-shortness is generally produced by the presence of sulphur, sometimes by arsenic, copper, and other impurities. The iron is tough when cold, but cannot be welded, and is difficult to forge at high temperatures.

17. Case-hardening.

When polished wrought iron is heated to a cherry red and placed in contact with broken prussiate of potash, scraps of leather, &c., the surface is converted into steel by absorption of carbon, and is then hardened by quenching in water. The nitrogen in the mixture is supposed to play an important part.

Other nitrogenous matters, such as bone-dust, horn, hoof and hide clippings, are often used. If heated with the mixture in a close box, the effect is greater. The case-hardening may extend to a depth of about $\frac{1}{16}$ inch. The surface shows a mottled appearance before re-polishing.

This method of hardening is used largely for motion blocks, links, pins and eyes, and generally for small articles or portions of them which have to stand much friction. It is cheaper than using steel, but the tendency of the articles to crack and twist is an objection.

18. Varieties of Steel. No. 1.

Steel may be made by the addition of carbon to wrought iron, or the abstraction of carbon from cast iron; both methods are in use commercially.

Blister Steel is produced by a process called cementation. Bars of purest wrought iron are placed in a furnace between layers of charcoal powder, and kept at a high temperature for from 5 to 14 days. The bars are now brittle, crystalline, and more or less covered with blisters. Small regular blisters and fine grain denote good quality. Used for facing hammers, &c., but not for edge tools; used largely for conversion into other kinds of steel.

Spring Steel is blister steel heated to an orange-red colour, and rolled or hammered.

19. Varieties of Steel. No. 2.

Shear Steel is blister steel cut into short lengths, piled into faggots, sprinkled with sand and borax, and placed at welding heat under a tilt hammer. "Single" and "double" shear steel denotes the number of times this process is repeated. Fibrous character now restored. Used for large knives, scythes, plane irons, shears, &c., frequently in conjunction with iron.

Crucible Cast Steel.—Originally made by melting fragments of blister steel in covered fireclay crucibles, and running into iron moulds. Now generally made direct from Swedish bars cut up and placed in crucibles, with small quantity of charcoal, with subsequent addition of spiegeleisen or oxide of

manganese. Variations on this process are known as Heath's and Mushet's, also Tungsten steel, Chrome steel, &c. Forged at low heat, unweldable, fracture grey, crystals very minute.

20. Varieties of Steel. No. 3.

Bessemer Steel.—Made from grey pig-iron containing a large proportion of free carbon, small quantity of silicon and manganese, free from sulphur and phosphorus. Iron melted in cupola, and run into a converter lined with fire-brick and suspended on hollow trunnions. Air blown through the metal about twenty minutes, removing all carbon; 5 to 10 per cent. spiegeleisen then added, and blowing resumed long enough to incorporate the two metals. Steel then run out into ladle and moulds. Ingots being porous are reheated and put under steam hammer, then rolled or worked as required. Used for rails, tyres, common cutlery and tools, roofs, bridges, &c.

Siemens Steel.—Pig-iron melted on furnace hearth; good ore and limestone are then added and heat kept up, process resulting in carbonic acid gas, slag, and steel.

21. Varieties of Steel. No. 4.

Siemens-Martin Steel.—Pig-iron melted in furnace, three or four times its weight of heated wrought-iron scrap or steel added, together with spiegeleisen or ferro-manganese, until required proportion of carbon, &c., is obtained, to give steel of requisite hardness; then run into ingot moulds.

Landore-Siemens Steel.—Iron ore is treated in a rotatory furnace with carbonaceous material, and converted into balls of malleable iron, which are transferred direct to steel-melting furnace. Spiegeleisen, &c., then added. The result is steel of very ductile quality, dense, and uniform in texture, and particularly suitable for replacing wrought-iron where increased strength is required, in addition to all the best properties of wrought iron.

22. Dannemora Cast Steel.

Carbon.	Temper.	Tools suited for	Remarks.
per cent. $1\frac{1}{2}$	Razor	Turning and planing, drills, &c.	Great skill required in forging, spoilt if overheated.
$1\frac{1}{4}$	Turning tool.	Turning, planing, and slotting tools, drills, small cutters, and taps.	Not weldable.
$1\frac{1}{8}$	Punch	Mill picks, circular cutters, taps, rimers, small shear-blades, large turning-tools and drills, punches, and screwing dies.	May be welded with great care.
1	Chisel	Cold chisels, hot setts, medium-size shear-blades, large punches, large taps, miners' drills for granite.	Will weld with care.
$\frac{7}{8}$	Sett	Cold setts, minting dies, large shear-blades, miners' drills; smiths' tools, as sett hammers, swages, flatteners, fullers, &c.	Will weld without difficulty.
$\frac{3}{4}$	Die	Boiler-cups, snaps, hammers, stamping and pressing dies, welding steel for plane-irons, &c.	Will weld like iron.

23. Notes on Cast Iron.

Stronger in compression than wrought iron, but much weaker in tension. Not so safe as wrought iron when subjected to impact or suddenly applied loads.

Used for complex parts of machines, because easier to mould in casting than wrought iron in forging. Principally for wheels, bed-plates, and framings.

If thickness of different parts varies much, the castings will be strained in cooling. All edges should be well rounded and hollows filleted.

Expands at moment of solidification in casting, but con-

tracts in cooling. Contraction varies with size and thickness of casting, and quality of metal.

24. Qualities of Cast Iron.

No. 1. *Grey.*—Soft. Deficient in strength. Used for ordinary castings. Very fluid when melted. 0·6 to 1·5 per cent. carbon chemically combined, 2·9 to 3·7 per cent. mechanically combined.

No. 2. *Mottled.*—Variable hardness. Stronger than No. 1. Used for larger castings. More carbon chemically combined, and less mechanically.

No. 3. *White.*—Hard. Fusible. Strong. Used for conversion into wrought iron. 3 to 5 per cent. of carbon all chemically combined.

These varieties are mixed in various proportions for special purposes.—*Unwin's Machine Design.*

25. Chilled and Malleable Cast Iron.

Chilled Cast Iron is ordinary cast iron rapidly cooled during solidification, by using a solid cast-iron mould protected by a wash of loam, causing a chemical combination of the molten iron and carbon. Very hard. Fracture silvery. Direction of crystallisation strongly marked.

Malleable Cast Iron is made by heating ordinary castings from two to forty hours, according to size, in contact with oxide of iron or powdered red hæmatite, causing partial conversion into wrought iron by abstraction of carbon.

26. Toughened Cast Iron.

Toughened cast iron is produced by adding to the cast iron, and melting amongst it, from one-fourth to one-seventh of its weight of wrought-iron scrap, which removes some of the carbon from the cast iron, and causes an approximation to steel.—*Notes on Building Construction*, iii. 252.

27. Copper.

Very malleable, and hence specially suited for hammering into thin hemispherical pans, rolling into sheets, &c., also ductile to a less degree. Rendered brittle by absorption of carbon, refined and toughened during manufacture, but may be spoilt again by careless manipulation. May be cast. Can be forged cold, or at red heat, but rapidly scales when hot. Addition of 2 to 4 per cent. of phosphorus improves its fluidity and tenacity. Used for fire-boxes, &c., because it is a good conductor of heat, but loses tenacity in proportion to its temperature. Much used in forming alloys.

28. Alloys.

Bronze is a mixture of (say) 10 copper, 1 tin.

Brass is a mixture of (say) 2 copper, 1 zinc.

Gun-Metal is a mixture of copper, tin and zinc in various proportions, according to the hardness or toughness required: say 16 copper, 2 tin, 1 zinc. May be also called bronze.

Muntz-Metal is a mixture of 3 copper, 2 zinc, and is therefore a brass.

29. Effect of Alloying with Copper.

Tin increases the hardness, and whitens the colour through various shades of red, yellow, and grey.

Zinc in small quantity increases fusibility without reducing the hardness, in greater quantity increases malleability when cold, but entirely prevents forging when hot.

Lead increases the ductility of brass, and makes alloy more suitable for turning, filing, &c.; in large quantity causes brittleness.

Phosphorus increases the fluidity and tenacity, reduces the effect of the atmosphere, and allows of tempering.

30. Bronze Alloys.

Name.	Copper.	Tin.	Zinc.
Soft gun-metal	16	1	..
Mathematical instruments	12	1	..
Pumps (very tough)	32	3	1
Small toothed wheels	10	1	..
Locomotive bearings	64	7	1
Engine bearings	112	13	¼
Locomotive straps and glands	130	16	1
Hard gun-metal for bearings	8	1	..
Baily's metal	32	5	2
G. M. for heavy bearings	32	5	1
Maximum hardness for bearings ..	5	1	..
Hydraulic valve faces	4	1	..
Bell metal	4 or 3	1	..
Speculum metal	2	1	..

31. Brass Alloys.

Name.	Copper.	Zinc.	Tin.	Lead.
Tough for engine work ..	100	15	15	..
For turning and fitting ..	3	1	..	$\frac{1}{12}$
Yellow brass	2	1	..	..
Stop cocks and valves	88	10	2	..
Flanges for brazing	32	1	..	1
Brass for soldering	8	3	..	..
Brass, various	60–92	8–40	¼–3	½–3
Muntz-metal sheathing ..	3	2	..	..
Do. locomotive tubes.. ..	66	33	..	1
Nails for sheathing	87	4	9	..
Statuary bronze	90	5	2	..
Red sheet brass	11	2	..	..

32. Antimony Alloys.

Name.	Copper.	Tin.	Lead.	Antimony.	Bismuth.
Babbitt's metal ..	1	10	..	1	..
Do.	1	24	..	2	..
Expanding alloy ..	..	..	..	2	1
Pewter	..	100	..	17	..
Type metal	..	..	3 to 7	1	..
White brass	1	..	7	7	..
Do.	3	90	..	7	..

33. Various Alloys.

Name.	Copper.	Tin.	Zinc.	Various.
Pot or cock metal ..	5	..	..	2 lead.
Cowper's metal ..	..	2	..	1 bismuth.
Aluminium bronze	90	..	..	10 aluminium.
Sterro-metal	60	2	35	3 wrought iron.
Gedge's metal ..	60	..	38·2	1·8 " "

34. Melting points of various Metals.

Wrought iron	3250° Fahr.
Steel	3250
Cast iron	2750
Copper	2000
Gun-metal	1900
Yellow brass	1850
Aluminium	1800
Antimony	810
Zinc	770
Lead	620
Bismuth	500
Tin	440

35. Weight of various Metals in pounds.

Name.	Cubic inch.	Cubic foot.
Gold	·70	1203
Lead	·41	710
Copper	·32	555
Gun metal	·31	530
Brass	·30	525
Muntz metal ..	·29	510
Steel	·28	490
Wrought iron ..	·28	480
Tin	·26	460
Cast iron	·26	450
Zinc	·25	435
Aluminium ..	·09	160

36. Use of Wood in Engineering.

Pattern-making.—American yellow pine, New Zealand pine, mahogany, alder, sycamore.

Bearings.—Lignum vitæ.

Brake Blocks.—Willow, poplar.

Buffer Beams.—Oak.

Floats for Paddle-wheels.—Willow, American elm, English elm.

Wheel Teeth.—Hornbeam, beech, holly, apple, oak if in damp place.

Sluice Paddles.—Oak, greenheart.

Joiners' Tools.—Beech, box.

Shafts and Springs.—Ash, hickory, lancewood.

Ordinary framing, piling, &c.—Yellow deal.

Carriage-building.—Teak.

Fender and Rubbing pieces.—American elm.

37. Fir, Deal, and Pine.

Fir is a general term for wood used in the rough, as distinguished from

Deal, a general term for wood wrought and used by the joiner.

Pine is another general term used for even grained stuff suitable for panels. Also for pitch pine.

Yellow deal and red deal are botanically classed as pine.

White deal and spruce deal are botanically classed as fir.

Deal is not a botanical term.

Planks, deals, and battens, are trade terms for boards of certain widths, viz., planks 11 inches, deals 9 inches, battens 4½ to 7 inches.

PART I.—SECTION III.

THE BEHAVIOUR OF MATERIALS UNDER STRAIN; THE STRENGTH OF BEAMS, SHAFTS, BRACKETS, ETC.

38. Classification of Strains.

Tension	Stretching or pulling.
Compression	Crushing or pushing.
Transverse Strain	Cross strain or bending.
Torsion	Twisting or wrenching.
Shearing	Cutting, or when acting along the grain of timber, detrusion.

39. Definitions of Strain and Stress.

Strain.—Every load which acts on a structure produces a change of form, which is termed the strain due to the load. The strain may be temporary or permanent, the former disappearing when the load is removed, the latter remaining as permanent set.

Stress.—The molecular forces, or forces acting within the material of a structure, which are called into play by external forces, and which resist its deformation, are termed stresses. —*Unwin's Machine Design.*

40. Testing Wrought Iron.*

The strength of a bar should be measured by the *work* done in producing rupture, i.e. the product of the elongation into the mean stress. A convenient approximation to relative toughness is obtained by observing the maximum stress and the elongation in a given length. The length formerly taken was 8 inches, but $6\frac{1}{4}$ inches is now usually adopted, so that the increase of length in sixteenths of an inch will

* See leaflet by the author on 'The Behaviour of Materials under Strain.'

represent the elongation per cent. The elongation being principally local, the percentage specified for a length of 8 inches $\times \frac{128}{100}$ or $1 \cdot 28$, will give the proper percentage for a length of 6 inches.

41. Factor of Safety

Is an amount fixed by practical experience, varying with the material used, and the manner of using. It is the ratio of the greatest safe stress to the ultimate resistance of the material, such as $\frac{1}{4}$, $\frac{1}{10}$ &c., and the calculated resistance of any section multiplied by the factor of safety suitable to the circumstances, will give the safe working load.

42. Proof Strength.

It was formerly supposed that the proof strength of any material was the utmost strength consistent with perfect elasticity; that is, the utmost stress which does not produce a *permanent set.* Mr. Hodgkinson, however, has proved that a set is produced in many cases by a stress perfectly consistent with safety. The determination of proof strength by experiment is now, therefore, a matter of some obscurity; but it may be considered that the best test known is, *the not producing an increasing set* by repeated application.—*Rankine's Applied Mechanics.*

43. Moments of Transverse Strength.

Moment of Load is the load multiplied by its effective leverage at the point required. The moment of a load divided by the depth of beam will give the horizontal strain on the extreme fibres in its upper and lower sides.

Moment of Resistance in a beam is proportional to the area of the fibres multiplied by the squares of their distances from the neutral axis.

Moment of Inertia is the sum of the moments of resistance in any given section.—*Hurst.*

44. Usual Allowance for Dead Load per Square Inch Sectional Area.

	Breaking Strain.	Safe Load.
Wrought Iron—		
Tension	22 tons	5 tons.
Compression	18 „	4 „
Cast Iron—		
Tension	7 „	$1\frac{1}{2}$ „
Compression	42 „	$7\frac{1}{2}$ „
Steel—		
Tension	35 „	8 „
Compression	50 „	12 „

45. Safe Load on Structures.

Cast-iron columns .. Cast-iron girders for tanks Wrought-iron structures	$= \frac{1}{4}$ breaking weight
Cast-iron for bridges and floors	$= \frac{1}{6}$ „
Stone and bricks	$= \frac{1}{8}$ „
Timber	$= \frac{1}{10}$ „

—*Molesworth.*

46. Safe Load on Floors.

Churches and public buildings,	$1\frac{1}{2}$	cwt. per	square foot
Warehouses	$2\frac{1}{2}$	„	„
Dwelling houses	$1\frac{1}{4}$	„	„

47. Weight of Men in Crowds.

Mr. Cowper found by experiment that a number of men averaged 140 lbs. per square foot.

Mr. Parsey considers that men packed closely would weigh at least 112 lbs. per square foot, but that in ordinary crowds 80 lbs. might be taken as sufficient.

On the continent it is not usual to estimate so high.

Belgians weigh about 140 lbs. each, Frenchmen 136 lbs., while Englishmen weigh 150 lbs.

Mr. F. Young states 80 lbs. per square foot is quite safe in practice.

Mr. Thomas Page packed picked men on a weighbridge with a result of 84 lbs. per foot super.

Mr. George Gordon Page says that for troops on march $35\frac{1}{4}$ lbs. per square foot is sufficient.

The usual practice is to assume the live load as 100 lbs. per square foot.—*A. T. Walmisley.*

48. Approximate Safe Load on Columns and Piers.

Oak post	up to 10 diameters long,	$\frac{3}{10}$	tons	per sq. in.
Fir "	" "	$\frac{2}{10}$	"	"
Cast-iron column or stanchion	" "	5	"	"
Do.	10 to 15 "	4	"	"
Do.	15 to 20 "	3	"	"
Do.	20 to 25 "	2	"	"
Do.	25 to 30 "	$1\frac{1}{2}$	"	"
Hard York or Portland stone piers		12	"	foot super.
Stock brick in cement (if covered with stone template		6	"	"
" " (without do.) ..		4	"	"

49. Weight of Materials for Estimating.

Wrought iron	480	lbs.	per cub. ft.
Cast iron	450	"	"
Gun metal	525	"	"
Lead	700	"	"
Greenheart	60	"	"
Oak	50	"	"
Fir	40	"	"
Granite	160	"	"
Bramley Fall and Hard York	140	"	"

50. Specification Tests of Cast Iron.
(Bridge and Girder Work.)

Three bars cast in dry mould from each melting, 3 feet 6 inches long, 2 inches deep, 1 inch wide; 3 feet between bearings, to break with average of 30 cwt. in centre, or minimum of 28 cwt., and to deflect not less than $\frac{3}{10}''$ with load of 25 cwt.

Samples prepared in lathe to bear $2\frac{1}{2}$ tons per square inch tensile strain before loss of elasticity, and to break with not less than 7 tons per square inch.

51. Specification Tests of Wrought Iron (Bridge and Girder Work).

Class.	Tons per square inch, Tensile Strength.	Elongation* per cent. at Twenty Tons.	Contraction per cent. at Point of Fracture.
Rivet iron	25	10	30
Rod and bar iron	24	$7\frac{1}{2}$	20
Angle and tee iron	22	6	15
Plates, with grain	21	$4\frac{1}{2}$	10
Plates, across grain	18	..	5

* In a length of 8 inches.

52. Specification Tests of Wrought Iron (Shipbuilding).

Class.	Tons per square inch, Tensile Strength.	Elongation* per cent. on Fracture.	Toughness.†
Rivet iron	26	25	650
Rod and bar iron	24	15	360
Angle and tee iron	22	$12\frac{1}{2}$	275
Plates, with grain	20	$7\frac{1}{2}$	150
Plates, across grain	19	6	114

* In a length of $6\frac{1}{4}$ inches.

† Should the actual elongation in sixteenths of an inch, multiplied by the stress in tons per square inch, upon rupture, be more than 10 per cent. under the amounts given in the last column, the iron will be rejected.

Cold bending in vice—$\frac{1}{2}$-inch plate 35°, $\frac{3}{8}$-inch plate 55°, $\frac{5}{16}$-inch plate 63°, $\frac{1}{4}$-inch plate 70°, rivet iron to double close, without cracking.

53. Designing Wrought Ironwork.

Limits of ordinary prices, Staffordshire district.

Plates.—Weight 5 cwt., length 15 feet, width 4 feet, 30 feet super, shape regular.

Angle and Tee Irons.—Length 40 feet, size 2½ inches by 2½ by 1¼ up to 8 united inches.

Bars.—(Round and square), diameter ½ inch to 3 inches, length 25 feet.

Bars.—(Flat), size 1 inch by ¼ inch up to 6 inches by 1 inch, length 25 feet.

Cleveland District.

Plates.—Weight 12 cwt., length 21 feet, width 4 feet 6 inches, shape regular.

53*. Comparative Strength of Iron and Steel Plates.

Quality.	Ultimate Tensile Strength.		Elongation per cent.	
	With Grain.	Across Grain.	With Grain.	Across Grain.
Mild steel	30	28	20	18
Best Yorkshire ..	24	22	12	7½
B. B. Staffordshire	22	19	9	5
B. "	20	18	6	2½

54. Ultimate Strength of various Metals and Alloys.

Name.	Tension. Tons per sq. in.	Compression. Tons per sq. in.
Aluminium bronze ..	25	..
Phosphor bronze	25	..
Muntz metal	20	..
Malleable cast iron ..	15	45
Copper (sheet and bolt)	15	..
Copper (cast)	10	..
Gun metal	12	48
Brass	10	5
Cast lead	6	3
Zinc	3	..
Tin	2	..

55. Limit of Elasticity.

The maximum strain per square inch sectional area, which any material can undergo without receiving a visible permanent set, is called its limit of elasticity.

The average limits of elasticity are—

Wrought iron, 10 tons. Cast iron, 2 tons. Steel, 15 tons.

And the average elongations under a strain of 1 ton per square inch are—

Wrought iron $\frac{1}{10000}$. Cast iron $\frac{1}{7500}$. Steel $\frac{1}{13000}$.

56. Modulus of Elasticity.

A bar in tension or compression is elongated or shortened by an amount proportionate to the strain, within certain limits. Assuming the elongation, on increasing the strain, to continue in the same ratio, a certain point would be reached where the bar would be increased to twice its original length. The weight in lbs. per square inch sectional area of the bar, to produce this result, is the modulus of elasticity. The amount varies with the kind and quality of the material employed.

57. Definitions of Modulus of Elasticity.

The modulus of direct elasticity of a material is the ratio of the stress per unit of section of a bar, to the elongation or compression per unit of length, produced by the stress.—*Unwin's Machine Design.*

It is the weight in lbs. that would stretch or compress a bar, having a sectional area of one square inch, by an amount equal to its own length, called Hooke's law.—*Cargill's Strains.*

58. Formula for Elongation by Elasticity.

M = Modulus of direct elasticity (see table).

l = Length in inches.

w = Load per square inch sectional area in lbs.
e = Elongation in inches,

$$e = \frac{w \times l}{M}.$$

59. Moduli of Elasticity.

	In lbs. per sq. in.
Cast steel, tempered	36,000,000
Steel, ordinary	30,000,000
Wrought-iron bar	29,000,000
Ditto plate	25,000,000
Cast iron	18,000,000
Copper	17,000,000
Phosphor bronze	14,000,000
Gun metal	10,000,000
Brass	9,000,000
Tin	5,000,000
Lead	720,000

60. Allowance in Bridges for Changes of Temperature.

Variation of 15° F. alters length of wrought iron as much as strain of 1 ton per square inch.

In exposed situations an allowance of $\frac{7}{16}$ of an inch movement, per 100 feet length, is necessary for the purpose of eliminating the strains due to change of temperature.—*Graham Smith.*

61. Resilience of Beams.

The resistance of beams to transverse impact, or a suddenly applied load, is termed their resilience. It is simply proportional to the mass or weight of the beam, irrespective of the length or the proportion between the depth and breadth.

Thus, if a given beam break with a certain steady load, a similar beam of twice the length will break with half the

load applied in the same way; but if the short beam be deflected or broken by a certain falling load, the long beam will require double the load dropped from the same height or the load dropped from twice the height, to produce the same effect.—*Anderson's Strength of Materials.*

62. Resilience.

Resilience or *Spring* is the quantity of mechanical work required to produce the proof-stress on a given piece of material, and is equal to the product of the proof strain or alteration of figure, into the mean load which acts during the production of that strain; that is to say, in general, very nearly one half of the proof load.

The *Resilience* or *Spring* of a *Beam* is the work performed in bending it to the proof deflection:—in other words, the energy of the greatest shock which the beam can bear without injury: such energy being expressed by the product of a weight into the height from which it must fall to produce the shock in question. This, if the load be concentrated at or near one point, is the product of half the proof load into the proof deflection.—*Rankine.*

63. Ultimate Strength of Timber.

Name.	Tension. per square inch	Compression. per square inch.
Ash	7½ tons	4 tons.
Beech	5 „	4 „
Elm	6 „	4 „
Riga fir	5 „	2½ „
Memel flir	5 „	2½ „
Larch	5 „	1½ „
Honduras mahogany	4½ „	3½ „
English oak	6 „	4 „
Dantzic „	5½ „	3½ „
Canada „	5½ „	3 „
Teak	7 „	5 „
Pitch pine	4½ „	..

64. Strength and Stiffness of Timber.

Name.	Stiffness.	Strength.	Resilience.
Ash	89	119	160
Beech	77	103	138
Riga fir	98	80	64
Memel fir	114	80	56
Larch	79	103	134
Honduras mahogany ..	93	96	99
English oak	100	100	100
Dantzic „	117	107	99
Canada „	114	86	64
Teak	126	109	94
Pitch pine	73	82	92

Oak being taken for comparison as = 100.

65. Proportions of Beams for Strength and Stiffness.

Strongest	Stiffest
$d : b :: \sqrt{2} : 1$	$d : b :: \sqrt{3} : 1$

Approximately for strength, d to b as 1 to ·7; and for stiffness as 1 to ·58; but 1 to ·5 is often used for beams, where the ends can be fixed sideways, because two can be cut out of a square log, and 1 to ·33 or three out of a square log when intermediate staying can be applied, as in joists.

66. Approximate Proportions of Beams.

Strength.	Stiffness.	Convenience.
inches.	inches.	inches.
$12 \times 8\frac{1}{2}$	12×7	12×9 or 12×6
10×7	10×6	10×5
$9 \times 6\frac{1}{2}$	$9 \times 5\frac{1}{4}$	9×6 or $9 \times 4\frac{1}{2}$
$8 \times 5\frac{1}{2}$	$8 \times 4\frac{3}{4}$	8×6 or 8×4
7×5	7×4	$7 \times 4\frac{1}{2}$ or 7×2
$6 \times 4\frac{1}{2}$	$6 \times 3\frac{1}{2}$	6×4
$5 \times 3\frac{1}{2}$	5×3	5×3
4×3	$4 \times 2\frac{1}{2}$	4×3 or $4 \times 2\frac{1}{2}$
3×2	$3 \times 1\frac{3}{4}$	3×2

67. Deflection and Camber.

Deflection is the displacement of any point in a loaded beam, from its position when the beam is unloaded.

Camber is an upward curvature, similar and equal to the maximum calculated deflection, given to a beam or girder or some line in it, in order to ensure its horizontality when fully loaded.

68. Deflection of Girders.

In girders with parallel flanges of uniform strength, the deflection produces a circular curve, the amount of deflection varies directly as the load $\times$ the sum of the areas of both flanges $\times$ the cube of the length, and inversely as the area of top flange $\times$ area of bottom flange $\times$ depth of web squared, or

$$\Delta = \frac{W \times (a_t + a_b) \times l^3}{a_t \times a_b \times d^2} \times c.$$

Common Rule.—Girders to be constructed with a camber of $\frac{1}{4}$ to $\frac{1}{2}$ inch per 10 feet of span, to allow for deflection when loaded.

69. Formula for Deflection of Wrought-iron Flanged Girders.

Of uniform strength, supported at both ends, and carrying distributed load. Strain allowed = 5 tons per square inch tension, 4 tons per square inch compression.

s = Span in feet.
d = Mean depth in inches.
Δ = Deflection in inches in centre.

$$\Delta = \frac{\cdot 0144\, s^2}{d}.$$

If depth $= \frac{1}{10}$ span, $\Delta = \cdot 012\, s$, $\frac{1}{12} = \cdot 0144\, s$, $\frac{1}{15} = \cdot 018\, s$.

70. Deflection of Beams.

Δ = Deflection in inches.
l = Length in feet.
b = Breadth in inches.
d = Depth in inches.
W = Load in cwts. in centre.
c = Constant =

Steel	700	Quebec oak	40
Wrought iron ..	500	Fir and deal	36
Cast iron	350	Dantzic oak	30
Teak	50	Pitch pine	26

Rectangular beam—

$$\Delta = \frac{l^3\,W}{b\,d^3\,c} \qquad W = \frac{\Delta\,b\,d^3\,c}{l^3},$$

$$b = \frac{l^3\,W}{d^3\,\Delta\,c} \qquad d = \sqrt[3]{\frac{l^3\,W}{\Delta\,b\,c}} \qquad b\,d^3 = \frac{l^3\,W}{\Delta\,c}.$$

Square beam, side $= \sqrt[4]{\dfrac{l^3\,W}{\Delta\,c}}$.

Cylindrical beam, diameter $= \sqrt[4]{\dfrac{l^3\,W}{\Delta\,c}} \times 1{\cdot}7$.

If load be uniformly distributed, deflection $= \frac{5}{8}\,\Delta$.
Cantilever with distributed load $= \Delta\ 6$.
Cantilever loaded at end $= \Delta\ 16$.
Safe deflection in timber $= \frac{1}{480}$ length, or $\frac{1}{40}$ inch per foot span.

71. Notes on Torsion and Shafting.

Torsion is measured by the load acting at 1 foot radius, which is required to fracture a specimen 1 inch diameter.

Torsion is similar to shearing, and could be calculated as

such, but it is more convenient to take it by leverage as above.

Strength varies as $\frac{d^3}{r}$, stiffness as $\frac{d^4}{l}$.

To run smoothly, long shafting must not twist more than 1° in 10 feet under maximum load.

Long shafts are not designed in strict accordance with rule, as they would then be tapered from driving end, involving extra assortment of driving pulleys.

Every alteration in diameter of a shaft, unless made at a coupling, must be made gradually by means of a curve at the junction of the two diameters.

Factor of safety, long shafts less than $4\frac{1}{2}$ inches diameter $= \frac{1}{10}$; short shafts and all over $4\frac{1}{2}$ inches diameter $= \frac{1}{6}$. Distance apart of supports in feet $= 5\sqrt[3]{d^2}$. Friction of ordinary shop shafting is about one horse-power per 100 feet.

72. Ultimate Torsional Strength of various Metals.

Round bars 1 inch diameter, load applied at 1 foot radius.

Cast steel,	average	1500 lbs.
Mild steel,	„	1200 „
Wrought iron,	„	800 „
Cast iron,	„	700 „
Wrought copper,	„	400 „

73. Transmission of Power by Shafting.

Strength of shaft to transmit power depends upon velocity: thus, shaft able to transmit 20 horse-power at 60 revolutions is sufficient for 60 horse-power at 180 revolutions. The explanation is, that the actual strain is the same in each case, the increase in horse-power being due to the increase in speed only. Power consists of pressure and velocity, and varies directly as the amount of each.

74. Formula for Strength of Shafting.

W = B. W. in lbs. at 1 foot radius, of shaft 1 inch diameter.

C = Coefficient of safety.

d = Diameter of shaft.

l = Leverage in feet.

s = Strain in lbs. at circumference of wheel.

$$d = \sqrt[3]{\frac{s\,l}{W\,c}} \qquad s = \frac{W\,d^2}{l} \times c.$$

75. Molesworth's Formula for Wrought-iron Shafting.

D = Diameter of shaft in inches.

$$K = \begin{cases} 320 \text{ for crank shafts and prime movers.} \\ 200 \text{ for second motion shafts.} \\ 100 \text{ for ordinary shafting.} \end{cases}$$

H = Actual horse-power to be transmitted.

n = Number of revolutions per minute.

l = Leverage in feet.

f = Force applied in lbs. at circumference of wheel.

$$H = \frac{2\,\pi\,l\,n\,f}{33000} \qquad H = \frac{D^3\,n}{K} \qquad f = \frac{D^3}{2\,\pi\,l} \times K.$$

$$f = \frac{33000\,H}{2\,\pi\,l\,n} \qquad D = \sqrt[3]{\frac{H}{n} \times K} \qquad D = \sqrt{\frac{2\,\pi\,l\,f}{33000} \times K}.$$

76. Proportions of Solid Wrought-iron Flange Coupling on Screw Shaft.

Let d = diameter of shaft. Then there should be eight bolts,* each $\frac{1}{4}\,d$ in diameter, the diameter of circle passing through the centres being $1\frac{1}{2}\,d$. The flanges should be $2\,d$ in diameter and $\frac{1}{4}\,d$ thick.—*Unwin.*

* Six bolts are commonly used, up to 6 inches diameter of shaft.

77. Transverse Strength of Shafts.

Load distributed on wrought-iron crank pin or overhanging journal in lbs., $c = 1200$.
Ditto, concentrated on shaft supported at ends, $c = 2400$.
Ditto, distributed „ „ „ $c = 4800$.

$$\text{Safe load} = c\,\frac{d^3}{l} \qquad d = \sqrt[3]{\frac{W\,l}{c}}.$$

Forces may be taken to act at the centres of journals in cases where supports are not contiguous to journals.

78. Proportions of Bolts, Whitworth Standard.

Diameter of Bolt in inches.	Width of Nut over Angles, approx. $= 1\frac{3}{4}$ diam. Approx. diam. of washer $\frac{1}{4}$ in. more.	Width of Nut over Sides, approx. $= 1\frac{1}{2}$ diam.	Diameter at top of Chamfering.	Thickness of Head.	No. of Threads per inch.
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{7}{16}$	12
$\frac{5}{8}$	$1\frac{1}{8}$	1	$\frac{15}{16}$	$\frac{1}{2}$	11
$\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{3}{16}$	$1\frac{1}{16}$	$\frac{5}{8}$	10
$\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$\frac{3}{4}$	9
1	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$\frac{7}{8}$	8
$1\frac{1}{4}$	$2\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{11}{16}$	1	7
$1\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{1}{4}$	2	$1\frac{1}{8}$	6
2	$3\frac{1}{2}$	3	$2\frac{5}{8}$	$1\frac{5}{8}$	$4\frac{1}{2}$
3	$5\frac{1}{4}$	$4\frac{1}{2}$	4	$2\frac{1}{2}$	$3\frac{1}{2}$

Thickness of nut = diameter of bolt.
Depth of thread = pitch.
Number square threads = $\frac{1}{2}$ number V threads.

79. Proportions of Bolts, Nuts, and Washers in Carpentry.

Thickness of nut	= 1	diameter of bolt.	
„ head	= $\frac{3}{4}$	„	„
Diameter of head or nut over sides	= $1\frac{1}{2}$	„	„
Side of square washer for fir ..	= $3\frac{1}{2}$	„	„

Side of square washer for oak .. = $2\frac{1}{2}$ diameter of bolt.
Thickness of washer .. .. .. = $\frac{1}{3}$ „ „

When the nuts are let in flush in fir, the washers should be same size as for oak.

80. Strength of Bolts.

Bolts in machinery subject to varying loads should not be strained to more than 2 tons per square inch of minimum section. A bolt 1 inch diameter being ·84 at bottom of thread will take not more than (say) 2000 lbs., including initial strain in screwing up.

Let d = outside diameter of thread in inches; $2000\ d^2$ = safe load in lbs. for 1-inch bolts and upwards; $2000\ d^3$ = safe load in lbs. for 1-inch bolts and under.

The ordinary force used in screwing up bolts is liable to break a $\frac{3}{8}$-inch bolt and seriously injure a $\frac{1}{2}$-inch bolt; hence bolts for joints requiring to be tightly screwed up should not be less than $\frac{3}{4}$ inch in diameter.

81. Strength of Bolts (Unwin).

		Per sq. in. net area.
Bolts not requiring to be tightened before load is applied	Safe load	= 6000 lbs.
Bolts accurately fitted and requiring to be tightened moderately	„	= 4000 „
Bolts used to draw joints steam tight and resist the pressure in addition ..	„	= 1600 to 2000 lbs.

82. To secure Check or Lock Nuts.

Put on check nut ($\frac{1}{2}$ diameter of bolt in thickness) screw up as tight against flange or work as an ordinary nut would be screwed under the circumstances, then put on ordinary

thick nut (1 diameter thick), screw it up with the same force and hold on to it with the spanner. Then with a thin spanner reverse the check nut against the other as far as it will go with about the same pressure as before. The check nut has then only the screwing-up force to resist, while the thick nut has in addition the strain which may be brought upon it by load or vibration.

83. Check Nuts.

. . . . This loosening of a nut can be prevented by adding another nut, which must be screwed hard down upon the first, to increase the pressure upon the thread.—*Willis' Mechanism.*

Note.—As described here, the second nut would only be equivalent to thickening the first nut, and would be useless as a check.

PART I.—SECTION IV.

THE ACTION OF CHISELS, HAMMERS, PUNCHES, PLANES, SHEARS, DRILLS.

84. Formulæ for Falling Bodies.

h = Height of fall in feet.
v = Velocity in feet per second.
g = Force of gravity = 32 (approximately).
t = Time of fall in seconds.

H = Highest point reached in feet.
T = Time to reach ditto.
V = Velocity imparted otherwise than by gravity.

Falling from Rest.	Thrown Downward.
$h = \frac{g t^2}{2} = \frac{1}{2} g t^2 = \frac{v^2}{2 g}$	$h = V t + \frac{1}{2} g t^2$
$v = g t = \frac{2 h}{t} = \sqrt{2 g h}$	$v = V + \sqrt{2 g h} = V + g t$
$t = \frac{v}{g} = \frac{2 h}{v} = \frac{\sqrt{2 h}}{g}$	$t = \frac{2 h g + V^2 - V v}{g v}$

Thrown Upward.

$$h = V t - \tfrac{1}{2} g t^2 = \frac{V^2}{2g} \qquad H = \frac{V^2}{2g}$$

$$v = V - \sqrt{2 g h} = V - g t \qquad V = \sqrt{2 g H}$$

$$t = \frac{2 h g + V^2 + V v}{v g} \qquad T = \frac{V}{g}$$

85. Holtzapffel's Classification of Cutting Tools.

Shearing tools act by dividing the material operated on into two parts, which separate from each other by sliding at the surface of separation.

Paring tools cut a thin layer or strip called a shaving from the surface of the work, and thus produce a new surface.

Scraping tools scrape away small particles from the surface of the work, thus correcting the small irregularities which may have been left by the paring tool.

86. Angles of Tools.

	Angle of Tool.	Speed of Cut.
For wood	30°–40°	8000 feet per minute.
„ wrought iron	60°	15–20 „ „
„ cast iron ..	70°	10–15 „ „
„ brass	80°	— „ „

Angle of relief for all tools, 5°–10°.

87. Cutting Speed of Machine Tools.

Steel	12 feet per minute
Cast iron ..	18 „ „
Brass	20 „ „
Wrought iron	24 „ „
Wood	2000 „ „ when material revolves.

Wood .. .. 3000 feet per minute when tool revolves.

Grindstone .. 800 feet per minute.

88. Speed of Machine Tools.

On soft cast iron ..	5 feet per minute.
„ steel and hard ditto	10 to 20 „
„ wrought iron ..	15 to 25 „
„ brass	40 to 100 „
„ wood	300 to 2000 „

—*Evers' Applied Mechanics.*

89. Speed of Machine Tools.

Speed of cut { Wrought iron, 20 feet per minute.
Cast iron, 16 „ „
Cuts per inch, 16 to 80.

For flat work—

Speed in inches per second × 5 = speed in feet per minute.

For small diameters—

Diameter in inches × revolutions in 16 seconds = speed in feet per minute.

For large diameters—

$$\frac{\text{Diar. in inches} \times 16}{\text{Seconds for 1 revolution}} = \text{speed in ft. per min.}$$

$$\frac{\text{Cutting speed in feet per min.} \times 5}{\text{Cuts per inch}} = \text{sq. ft. tooled per hour.}$$

—*Engineering*, 21st Nov. 1879.

90. Shearing and Punching.

Resistance to shearing of wrought iron averages 50,000 lbs. per square inch area of surface cut. This will be the pressure required on the material at the commencement of the stroke.

The mechanical work in punching or shearing is estimated by Weisbach as this pressure exerted through $\frac{1}{6}$th the thickness of the plate, and the coefficient or modulus of the machine as ·66, the friction being taken at 33 per cent. of the gross pressure.

91. Shearing and Punching.

Formula for calculating power required:

t = Thickness of plate or bar.
l = Length or circumference of cut.
f = Resistance of material to shearing.
M = Modulus of machine, say ·66.
P = Gross pressure in lbs.

$$P = \frac{t\,l\,f}{M}$$

92. Pressure required to Punch Wrought-iron Plates.

(From experiments).

	d.		*t.*		P.		*c.*
To punch	$\frac{1}{8}$ hole	in	$\frac{1}{8}$ plate	requires	$2\frac{1}{4}$	tons =	144
Do.	$\frac{1}{4}$	"	$\frac{1}{4}$	"	$6\frac{1}{2}$	"	104
Do.	$\frac{3}{8}$	"	$\frac{3}{8}$	"	13	"	92
Do.	$\frac{1}{2}$	"	$\frac{1}{2}$	"	22	"	88
Do.	$\frac{5}{8}$	"	$\frac{5}{8}$	"	$33\frac{1}{2}$	"	86
Do.	$\frac{3}{4}$	"	$\frac{3}{4}$	"	$47\frac{1}{4}$	"	84
Do.	$\frac{7}{8}$	"	$\frac{7}{8}$	"	$62\frac{3}{4}$	"	82
Do.	1	"	1	"	80	"	80

$$P = d \times t \times c.$$

Approximately diam. × thickness × 88 = pressure in tons;
or, area of cut surface × 28 = ditto

93. Laws of Friction.

The friction between two surfaces, dry or only slightly greasy, is in direct proportion to the force with which they are pressed together (within the limits of abrasion), and is

independent of the area of the surfaces in contact. With ample lubrication the friction is reduced, but the heavier the pressure per unit of surface the greater must be the consistency of the lubricant, to prevent it from being squeezed out.

The friction between two surfaces at rest is slightly greater than when they are in motion, but when in motion the friction is independent of the velocity so long as the surfaces are kept cool.

94. Definitions of Friction.

The Limiting angle of Resistance ϕ is the angle through which any surface requires to be lifted from the horizontal to cause a body to be on the point of sliding (friction of rest) or to continue sliding (friction of motion). Its magnitude is fixed by the physical nature of the surfaces in contact. It is also the angle from the vertical made by the resultant of the force or forces acting upon a body when sliding is just about to take place or is taking place.

The Coefficient of Friction μ is the ratio of the pressure P required to overcome the friction of a body on any given horizontal surface, to the whole load W of and on the body $\left(\mu = \frac{p}{W}\right)$. Trigonometrically it is equal to the tangent of the limiting angle of resistance (μ = tangent ϕ).

95. Mean Coefficients of Friction.

Wood on wood or metal—dry, ·4 to ·6; greasy, ·2 to ·4; lubricated, ·1 to ·2.

Metal on metal—wet, ·3; dry, ·2; greasy, ·15; lubricated, ·1 standing, or ·08 moving.

Leather on metal, wet ·25, dry ·5.

Friction of motion = friction of repose × ·7.

Friction varies with the nature of the surfaces, the lubricant, and the temperature.

96. Morin's Experiments on Friction of Motion.

Dry—							
Wrought iron on brass			·172	Brass on wrought iron			·161
Cast	„	„	·147	„	cast	„	·217
Greasy—							
Wrought	„	„	·160	„	wrought	„	·166
Cast	„	„	·132	„	cast	„	·107
Lubricated with olive oil—							
Wrought	„	„	·078	„	wrought	„	·072
Cast	„	„	·078	„	cast	„	·077

Oak upon elm dry = $\frac{5}{8}$ of friction of elm upon oak dry.

Note.—These results reduced from General Morin's experiments appear to be very questionable, and indicate the necessity for further investigation.

PART I.—SECTION V.

OPERATIONS OF TEMPERING, WELDING, RIVETING, CAULKING, &c.

97. Forging.

Wrought iron at a red heat may be hammered into various shapes, called "forging." When a piece is drawn down smaller it is called "swaging;" if jumped up thicker, it is called "upsetting." Common iron is not suitable for forging, as the scale or slag in it causes cracks. Double and treble best Staffordshire and ordinary Yorkshire are suitable. The best Yorkshire is used for flanging and difficult forgings. Charcoal iron for light and complicated work.

Steel may be forged gradually at a low heat. The greater

the proportion of carbon contained, the greater the difficulty of forging. All forging should proceed by easy stages, and care be taken not to burn the iron or steel.

98. Welding

Is the process of joining two pieces of wrought iron or steel by heating, and hammering them together. To weld iron the pieces must be brought to a white heat, and the scale swept off before they are put together. Steel requires a much lower heat, and the surfaces should be sprinkled with sand or borax. The welding temperature depends upon the amount of carbon contained: hence, the extra difficulty of welding two pieces of different composition. Mild steel approaches wrought iron in its welding qualities. Steel faces may with care be welded on to iron tools; shear steel is generally used for this purpose.

99. Tempering.

Steel when heated to a cherry red, and suddenly cooled in water or oil, is rendered very hard. Some suppose that the carbon is caused to take the crystalline or diamond form. For tempering the hardened steel a portion is brightened with a piece of broken grindstone, and then reheated until the film of oxide formed on the surface shows the requisite temperature; it is then quenched in water, and the hardness is found to be "let down" to the "temper" required. Tempering was formerly considered to be the only true test of steel.

100. Colours corresponding to Temperature.

	Deg. Fahr.		Deg. Fahr.
Faint red	960	Orange	2010
Dull red	1290	Bright orange	2190
Brilliant red	1470	White heat	2370
Cherry red	1650	Bright white heat	2550
Bright cherry red	1830		

—*Becquerel.*

101. Tempering Steel.

Colours produced at various Temperatures, and Alloys fusible at same.

Colour of Film.	Temp. Fahr.	Nature of Tool.	Lead.	Tin.
None	400°	.. .. ..	22	16
Very pale straw yellow	430	Lancets and turning-tools for metal	30	16
A shade of darker yellow	450	Razors and ditto	34	16
Darker straw yellow	470	Penknives	42	16
Still darker straw yellow	490	Cold chisels, drills, screw taps, wood tools	56	16
Brownish yellow	500	Hatchets, plane-irons, chipping-chisels, saws for	66	16
Yellow tinged with purple	520	iron, tools for working granite	100	16
Light purple	530	Swords, ordinary springs, tools for cutting sand-	120	16
Dark purple	550	stone	192	16
Dark blue	570	Small saws, watch-springs	..	..
Pale blue	600	Large saws, pit and hand saws	..	..
Pale blue with tinge of green	620	Too soft for steel instruments	All	0

102. Notes on Riveted Joints.

Hard wrought iron is weakened from 15 to 30 per cent. by punching.

In punched plates the small sides of the holes should come together.

Drilled holes should have the edges chamfered.

The tension in a rivet may be estimated at 21,000 lbs. per square inch of its section.

Friction due to this tension would be about 7000 lbs. per square inch of rivet section.

The usual diameter of rivets in hand riveting varies from $\frac{1}{2}$ inch to $\frac{7}{8}$ inch.

In machine riveting they may be used up to $1\frac{1}{4}$ inch diameter.

Maximum efficiency of single riveted joint = $\frac{2}{3}$ strength of plate.

Maximum efficiency of double riveted joint = $\frac{4}{5}$ strength of plate.

103. Notes on Caulking.

Caulking consists of burring up the inner edge of the plates in a joint by means of a tool like a flat-ended chisel, to prevent leakage in boilers, tanks, &c.

Plates with rough sheared edges should be chipped even, to a slight bevel, before caulking.

Joints appearing at all open should be closed by a flogging hammer before caulking.

When the caulking is done on one side only, it should be upon the same side as the riveting. In best work the joints are caulked inside and out.

When the lap exceeds three times diameter of rivet the caulking is apt to open the joint, unless done very lightly.

104. Caulking Tools.

The caulking tool should be flat-ended and slightly bevelled, from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch thick × 1 inch to $1\frac{1}{4}$ inch

wide, with one edge square and the other rounded to prevent cutting into the plate.

The rounded edge should be held next to the plate the first time of going along the joint, called splitting the lap, and afterwards reversed.

The finished caulking should appear like a parallel groove about $\frac{1}{32}$ inch deep × $\frac{1}{8}$ inch wide in a $\frac{3}{8}$-inch plate.

PART I.—SECTION VI.

TOOLS USED IN THE WORKSHOP, MACHINES USED FOR LABOUR-SAVING IN THE CONSTRUCTION OF SMALL MACHINERY, AS MILLING, STAMPING, AND SCREWING MACHINES.

105. Workshop Tools

Are divided into two classes, hand tools and machine tools. In the former are included hammers, chisels, files, ratchet braces, spanners, &c., and in the latter lathes, planing, shaping, drilling, and slotting machines, &c., in the fitting shop; and punching and shearing machines, bending rolls, steam hammers, &c., in the smiths' shop.

The machine tools are now mostly driven by steam power through shafting connected by belts.

A workshop should be so arranged that the raw material coming in at one end should be received at the various tools in the order of the work to be done upon it, and be removed in a finished state at the other end.

PART II.

FOUNDING, MOULDING, AND PATTERN-MAKING.

106. Pattern-making.

Small patterns made of mahogany or New Zealand pine. Larger patterns made of white or yellow pine. Metal patterns used where a great number of similar castings are required. Wood patterns coated with red or black varnish, to prevent distortion from damp sand.

Patterns should have rounded edges, and filleted angles wherever possible. The thickness of metal throughout a casting should be as uniform as possible, changes of direction being avoided. Sharp corners in a casting are always weak. Sufficient taper must be given to draw out of the sand, and allowance made for knocking to loosen in mould.

107. Moulding in Foundry.

Green-sand Moulding.—Used for light iron castings, firebars, rough machine castings, &c. The ordinary damp sand of the foundry is used in iron boxes or "flasks" for receiving impression from "patterns," the hollow parts being formed of baked sand "cores." Long cores are supported by "chaplets," small and complicated cores are made of "loam."

Dry-sand Moulding.—Used for ornamental ironwork, important machine castings, and for casting in brass. The sand consists of fresh sand mixed with loam which has been used or of fresh sand only. When finished, the moulds are dried for several hours. "Blackening" prevents sand melting.

Loam Moulding.—Used for steam cylinders, bent pipes, and complicated work. The mould is often built up without patterns, and consists of brickwork coated with loam and

"swept" to required shape by a "loam-board." Long straight cores are formed of iron pipe with haybands twisted on to hold the loam, and other cores of loam strengthened by bent "core-irons." The loam is common brick-clay mixed with horse-dung, cow-hair, sand, &c.

108. Sand for Moulding.

Moulding Sand consists of 93 to 96 per cent. of sharp sand and 3 to 6 per cent. of clay. Quality varies for different castings. The smaller the castings, the more clay the sand may contain. Heavy castings require poorer and coarser sand. Coal and coke are used to make the sand more porous, makes the castings rougher, but by giving free vent to the gases makes them sounder.

Parting Sand is the burnt sand scraped off castings, and is used to facilitate the division of the upper and lower boxes in moulding.

Core Sand consists of 90 per cent. sharp sand and 10 per cent. of clay, and should be used fresh.

109. Foundry Drying Stove.

Brick chamber of three sides with arched top shut with close iron doors on fourth side. Size about 10 feet × 10 feet × 7 feet high. Fire-place on one side, flue near ground on opposite side, fire fed through a door on outside. Iron shelves on walls for drying small cores and boxes. Rails run from crane into drying stove, so that large moulds may be wheeled in. Stoves of various sizes in large foundry, the larger ones only used when required for very large moulds.

110. Cleaning Castings.

Moulds taken apart and sand removed as soon as castings have set, castings taken out with tongs and left to cool, time

varying according to weight and mass. Gates and partings broken off, and heavy or hard cores removed in foundry before casting is cold. Projections removed in cleaning shop with chisel, sharp hammer, or worn-out file, and casting well brushed with steel wire brush. Holes stopped with black putty, cement, or lead, and castings painted with black wash. The scrap averages 25 per cent. of the castings, less on large work.

111. Classification of Iron Ores.

Mr. Truran classifies the ores of Great Britain into four great divisions, thus :—

A. The argillaceous ores of the coal formations, having clay, but sometimes silica, as the chief impurity.

B. The carbonaceous ores of the coal formations, distinguished by their large percentage of carbon.

C. The calcareous or spathic ores, or the sparry carbonates of iron, having lime as their chief earthy admixture.

D. The siliceous ores, having silica as their predominating earth. This class is subdivided into the red and brown hæmatites, the ores of the oolitic formation, the white carbonates, and the magnetic oxides.

112. Charges employed at Dowlais for different kinds of Pig-Iron.

	Foundry Pig.	White Forge Pig.	Common Forge Pig.
	cwt.	cwt.	cwt.
Calcined " mine " (fresh ore)	48	28	..
Red hæmatite ore..	..	10	16
Forge and refinery cinder ..	..	10	25
Limestone	17	14	16
Coal	50	42	36
Weekly make	130 tons.	170 tons.	190 tons.

113. Analyses of Pig-Iron.

Carbon, partly combined, and partly in a graphitic form	2·3 to 5·5
Silicon	0·13 „ 5·7
Manganese	0·0 „ 7·6
Sulphur	0·0 „ 0·87
Phosphorus	0·0 „ 1·66

114. Foundry Pig.

No. 1 Pig is chiefly used in the foundry. Colour dark grey, crystals large and leafy, carbon in form of graphite. Very soft, melts very fluid, but being coarse grained, will not give a sharp impression. Cools slowly. For fine castings the presence of a little phosphorus is advantageous: the grain is finer, the iron a lighter colour, and the impressions sharper. Used for small castings, hollow ware, small machinery, &c.

No. 2 Pig, grey and mottled in colour. Used for large castings in dry sand or loam. Melts fluid, is tough, close texture, fills the mould well, more free from impurities than No. 1. Heavy machine castings made from No. 2, or various mixtures of 1, 2, and 3.

No. 3 Pig, hard and white, used for mixing.

115. Mixtures of Pig-Iron.

Mixture recommended for girders, &c., where rigidity and strength are required:—

Lowmoor, Yorkshire No. 3	30 per cent.
Blaina or Yorkshire No. 2	25 „
Shropshire or Derbyshire No. 3 ..	25 „
Good old cast scrap	20 „
	100

—*Fairbairn.*

116. Melting Metal for Castings.

Crucibles are sometimes used for melting iron for trinkets and small goods. The best castings, whether iron, bronze, or other metal, for machine frames, bells, statues, &c., are made from a *reverberatory furnace*, run directly from the furnace in dry sand ditches to the mould. The *cupola* has the advantage of melting iron cheaper than any other furnace; where strength is unimportant, it is the best method.

117. Contraction of Metals in Cooling.

Metal.	Contraction. In Fractions of Linear Dimensions.	Contraction. In Parts of an Inch per Foot of Linear Dimensions.
Cast iron	$\frac{1}{96}$	$\frac{1}{8}$
Gun metal	$\frac{1}{72}$	$\frac{1}{6}$
Yellow brass	$\frac{1}{64}$	$\frac{3}{16}$
Copper	$\frac{1}{60}$	$\frac{1}{5}$
Zinc and Tin..	$\frac{1}{48}$	$\frac{1}{4}$
Lead	$\frac{1}{89}$	$\frac{5}{16}$

118. Contraction of Castings.

Heavy pipes	$= \frac{1}{8}$	inch	per foot.
Girders, beams, &c.	$= \frac{1}{8}$	,,	in 15 inches.
Engine beams / Connecting rods	$= \frac{1}{8}$	,,	in 16 inches.
Large cylinders, say 70 inches diameter × 10 feet stroke, the contraction of diameter	$= \frac{3}{8}$	,,	at top.
	$= \frac{1}{2}$	,,	at bottom.
Ditto in length	$= \frac{1}{8}$	,,	in 16 inches.
Small narrow wheels, about	$= \frac{1}{25}$	,,	per foot diam.
Large heavy wheels	$= \frac{1}{10}$	,,	or more ,,
Thin brass	$= \frac{1}{8}$	,,	in 9 inches.
Thick brass	$= \frac{1}{8}$	,,	in 10 inches.

Zinc and lead, each	= $\frac{5}{16}$ inch per foot.	
Copper	= $\frac{3}{16}$,, ,,	
Bismuth	= $\frac{5}{32}$,, ,,	
Tin	= $\frac{1}{4}$,, ,,	

Pattern-makers commonly allow for iron castings $\frac{1}{8}$ inch per foot, and for brass castings $\frac{3}{16}$ inch per foot.

119. Bronze and Brass Castings.

Melted in crucibles, wasting prevented by covering surface with mixture of potash, soda and charcoal powder. Copper melted first, then tin, then zinc or antimony, then covering applied. Zinc is best added in form of brass, calculating the copper contained. Large strong castings require the metal exposed to fire in fluid state 8 or 10 hours, proof taken by small ladle and broken when cool, judged by crystallisation, and copper or tin added as required. Before casting, bronze is well stirred with heated iron rods. Brass made by melting together copper scraps, crude zinc or spelter, and charcoal powder, remelted for casting.

PART III.

SHAFTING, GEARING, AND GENERAL MACHINERY.

120. Transmission of Motion.

By *rolling contact*, as spur wheels and pinions, crown wheel and pinion, face wheel and lantern, bevil wheels, cones, rack and pinion, &c.

By *sliding contact*, as inclined plane, wedge, cams, swash plate, crown wheel escapement, screw, &c.

By *wrapping contact*, as cords and pulleys, belts and pulleys or riggers, speed pulleys, capstan, fusee of watch, &c.

By *link work*, as levers, cranks, treadle of lathe, &c.

—*Tomkins' Machine Construction.*

121. Useful Work and Efficiency.

Useful work of a machine is that performed in producing the effect for which the machine is designed.

Lost work is that performed in producing other effects.

The *power* of a machine is the energy exerted, and the *effect* the useful work performed, in some interval of time of definite length.

The *efficiency* of a machine is a fraction expressing the ratio of the useful work to the whole work performed or energy expended. This ratio is also called the *modulus* or *coefficient* of the machine.

The *counter-efficiency* is the reciprocal of the efficiency, and is the ratio in which the energy expended is greater than the useful work.—*Rankine's Applied Mechanics.*

122. Velocity Ratio.

The *velocity ratio* in any machine is the proportion between the movement of the power and the movement of the resistance, in the same interval of time; for example, in a punching press it may be 100 to 1 $= \frac{100}{1}$, and in a hydraulic crane 1 to 8 $= \frac{1}{8}$. These proportions also express the amount of the resistance (including friction), compared with the power or pressure applied. (See definition of *virtual velocity.*)

The term *purchase* of a machine is applied either to the motion or pressure of the resistance compared with the power; in above examples, the purchase of the punching press would be 100, that of the hydraulic crane 8, but the term is generally restricted to the gaining of pressure by the sacrifice of speed, as in the first case.

123. Principle of Virtual Velocities.

If any machine without friction be in equilibrium and the whole be put in motion, the initial pressure P will be to the

final pressure p as the final velocity V is to the initial velocity v, or $P : p :: V : v$, or $p\,V = P\,v$.

In practice, as all machines have friction, p will depend upon the friction, but V will be in accordance with the calculation of the leverage or gearing.

Let e = the final pressure by experiment, then $p - e$ = friction, and the coefficient or modulus of machine $M = \frac{e}{p}$.

124. Definitions of the Principle of Virtual Velocities.

Rankine's.—The effort and resistance are to each other inversely as the velocities, along their lines of action, of the points where they are applied.

Twisden's.—If a system of pressures, in equilibrium, act on any machine which receives any small displacement, consistent with the connection of the parts of the machine, the algebraical sum of the virtual moments of the pressure will equal zero.

125. Angular Velocity.

The angular velocity of a wheel is the speed of a point in the circumference of an imaginary wheel with unity as radius, and making the same number of revolutions per minute as the given wheel.

Velocity is taken in feet per second.
Revolutions are taken at per minute.

$$\text{Circumferential velocity} = \frac{2\,\pi\,r\,n}{60} = \frac{\pi\,r\,n}{30} = \cdot 10472\,r\,n.$$

$$\text{Angular velocity} = \frac{2\,\pi\,r\,n}{60} = \frac{\pi\,n}{30} = \cdot 10472\,n.$$

126. Notes on Belt Gearing (No. 1).

Coefficient of friction between ordinary leather belting and cast-iron pulleys or drums = ·423. Ultimate strength of ordinary leather belting = 3086 lbs. per sq. in. Belts vary from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch thick, average $\frac{7}{32}$ inch.

	Breaking Strain.	Safe Working Strain.
Through solid part ..	.. 675 lbs. ..	225 lbs. per in. wide
Through riveting ..	.. 382 lbs. ..	127 " " "
Through lacing	.. 210 lbs. ..	70 " " "

The working strength of the belt must be taken as that of its weakest part, which is the lacing.

The tension of the driving side, which must not exceed the safe working strength of the belt = force transmitted + mean normal tension.

The force transmitted = the difference between the tension of the driving side and the tension of the following side.—*Welch's Designing Belt Gearing.*

127. Notes on Belt Gearing (No. 2).

When the arc of contact = 180°, the force able to be transmitted may be taken as 50 lbs. per inch wide. If more or less than $\frac{1}{2}$ circumference be embraced by belt, the force transmitted may be increased or reduced by about 2·8 lbs. for every 10° difference from 180°.

The sum of the tensions, or cross strain on shafting, may be taken as 90 lbs. per inch wide.

The lower side of a belt should be made the driving side when possible, so that the arc of contact may be increased by the sagging of the following side. The actual horse-power capable of being transmitted by a belt = ·0015 × velocity in feet per min. × breadth in inches.

To increase the capability for transmission of power, the diameters of the pulleys may be increased, retaining the same ratio, the increase of power being obtained by the increased velocity alone.

128. Notes on Belt Gearing (No. 3).

Approximate rule for width of single leather belt, say $\frac{3}{16}$ inch thick $= \dfrac{1100 \text{ H.P.}}{v. \text{ ft. per min.}}$

For double belting take $\frac{6}{10}$ths of width of an equivalent single belt.

Wide belts are less effective per unit of sectional area than narrow belts. Long belts are more effective than short belts.

A belt should never exceed 18 inches wide.

The velocity of lathe belts should be from 25 to 33 feet per second, = 1500 to 2000 feet per minute.

Convexity of pulleys to receive belt = $\frac{1}{2}$ inch per foot wide.

The proportion between the diameters of two pulleys working together should not exceed 6 to 1.

Width of pulley = $\frac{1}{4}$ more than belt.

129. Notes on Ropes.

Italian hemp ropes are stronger than Russian hemp.

New white ropes are stronger and more pliable than tarred ropes, but the latter retain their strength for a longer period.

Tarred ropes are stiffer than white by about $\frac{1}{6}$, and in cold weather somewhat more.

Ropes which have been some time in use are more flexible than new ones; the stiffness of ropes increases after a little rest.

Wet ropes, if small, are a little more flexible than dry; if large, a little less flexible. Ropes shorten and swell when wetted.

There is considerable loss of strength from strain, and exposure after use, although a rope may appear perfectly sound.

Ropes are usually measured by their circumference: hence

a 6-inch rope is one 6 inches in circumference, or about $1\frac{7}{8}$ inch diameter.

All ropes should be kept dry and free from lime.

130. Strength of Ropes.

Ultimate strength of new white ropes is about 6000 lbs. per square inch sectional area, but good ropes may stand 1000 lbs. per square inch.

Double rope slings are not twice the strength of single rope, owing to inequality of strain; but in a rope fall with sheaves in good order, each fold of the rope may be counted for the strength.

The work absorbed in bending a rope fall over a sheave varies with the size and quality of the rope, the diameter of the rope, the diameter of the sheave, and the tension in the rope.

Include weight of running block in calculating load on fall, and both blocks together with the rope, in weight on strop.

Snatch block makes practically no difference in lifting power, if it has a good lead.

131. Formulæ for Strength of Ropes.

Breaking weight new rope, cwts.	=	circumference^2 × 5.
Safe load on ,, ,,	=	wt. lbs. per fath. × 3.
B.W. new stretched rope in ,,	=	(diameter in $\frac{1}{8}$ths)^2.
Safe load ,, ,,	=	wt. lbs. per fath. × 4.
,, on new rope fall ,,	=	circumference^2.
,, good ,, ,,	=	$\frac{2}{3}$,,
,, old ,, ,,	=	$\frac{1}{2}$,,
Weight of clean dry rope per fathom, in lbs.	=	$\frac{1}{4}$,,
Minimum diameter of sheave in inches.	=	circf. rope + 2 ins.

132. Strength of Chains.

d = Diameter of Iron in ⅛ths of an Inch.			Example ¾ Chain. tons	cwts.
B.W. in tons, B.B. short-link crane chain ..	=	$\frac{1}{2}d^2$	18	0
„ „ ordinary chain	=	$\frac{2}{5}d^2$	14	8
„ „ ordinary chain (Anderson) ..	=	$\frac{3}{8}d^2$	13	10
Elswick test in tons, 10 per cent. above Admiralty proof	=	$\frac{33}{160}d^2$	7	8½
Admiralty proof strain in tons	=	$\frac{3}{16}d^2$	6	15
Safe load in tons (Molesworth, p. 215, eleventh edition)	=	$\frac{1}{8}d^2$	4	10
Safe load at 5 tons per square inch sectional area	=	..	4	8½
„ in tons, common rule	=	$\frac{1}{10}d^2$	3	12
Maximum temporary load on good annealed chain in cwts.	=	$2d^2$	3	12
Safe load, ordinary chain (Anderson), in tons..	=	$\frac{3}{32}d^2$	3	7½
„ for ordinary cranes, in cwts.	=	$1\frac{1}{2}d^2$	2	14
„ at 3 tons per square inch sectional area	=	..	2	13
„ coal cranes, in cwts.	=	$1\frac{1}{4}d^2$	2	5
„ old chain, quality and condition unknown	=	d^2	1	16
Weight in lbs. per fathom, short-link crane chain	=	d^2	36	
„ „ ordinary „	=	$\cdot 88d^2$	31½	

133. Remarks on Crane Chains.

$\frac{9}{16}$″ B. B. tested short link crane chain (Crown S. C.) should break with a load of 13 tons, if the iron bar from which it is made break with 26 tons per square inch ultimate stress; but a test piece of the chain 4 feet long breaks usually with a load of 9 to 10 tons, generally opening at the welds. Each chain is tested before use with a maximum load of 4½ tons, examined link by link and used on Hydraulic Coal Cranes to lift maximum gross load of 1¼ tons, examined again at frequent intervals and annealed; any links reduced by wear to ½ an inch at ends are condemned as worn out; worn links cut out and remainder used down to same limit. A good chain, properly looked after, will make from 100,000 to 150,000 lifts before it is entirely worn

out. These chains occasionally fail in use, although the factor of safety adopted allows so great a margin.

134. Wheel Gearing, Manchester Pitch.

Diametral pitch (Manchester pitch) =

$$\frac{\text{No. of teeth}}{\text{Diam. of pitch circle in ins.}}$$

$$\text{Circular pitch} = \frac{\pi}{\text{diametral pitch.}}$$

or (tooth + space) in inches.

No. of teeth in wheel = diameter × diametral pitch.

$$\text{Diameter of wheel} = \frac{\text{No. of teeth}}{\text{diametral pitch}}.$$

Addition to diameter for increased No. of teeth =

$$\frac{\text{No. to be addded}}{\text{diametral pitch}}.$$

$$\text{Outside diameter of wheel} = \frac{2}{\text{diametral pitch}} +$$

diameter pitch circle.

135. Notes on Toothed Gearing (No. 1).

Pinions, wheels, and racks are made of cast iron, cast steel, and malleable cast iron; the latter is strong, but liable to twist or warp. Pinions are sometimes made of wrought iron; small gearing is frequently made of gun metal.

Gearing is increased in strength by shrouding or flanging up to pitch line.

The comparative wear of gearing is inversely proportional to the number of teeth; hence, pinions wear quicker than wheels.

Two teeth on a pinion or wheel is the minimum number in gear at one time.

The *power* capable of being transmitted by gearing depends, within reasonable limits, entirely upon the *speed*; the *pressure* (at pitch line) depends upon the *pitch.*

136. Notes on Toothed Gearing (No. 2).

The transmission of the power strains the teeth as cantilevers, or $s = \frac{b\ d^2}{l}\ c$, c for cast iron safe load $= 600$.

The working load should not exceed $\frac{1}{10}$th of the breaking weight.

The dimensions of the teeth are proportional to the pitch; hence, in ordinary proportions the strength is represented by $p^2\ c$, c for cast iron being 1000.

The breadth of tooth on face beyond a certain amount, say twice the pitch, cannot be reckoned upon for strength, owing to irregularities in the teeth, and probability of unequal bearing.

137. Strength and Weight of Toothed Gearing.

Safe pressure in lbs. at pitch line on wheel teeth of average proportions:—

Cast iron,	little shock,	$= 625 \times \text{pitch}^2$.
„	moderate shock,	$= 400 \times \text{pitch}^2$.
„	excessive shock,	$= 277 \times \text{pitch}^2$.

The latter case also applies to the iron teeth of mortise wheels, which are made thinner than ordinary teeth of same pitch.

Breadth of teeth $= 2$ to $2\frac{1}{2}$ times pitch.

The weight of toothed gearing in lbs. approximately, is for spur wheels $\cdot 38\ n\ b\ p^2$, Bevil wheels $\cdot 325\ n\ b\ p^2$.

138. FORMULÆ FOR STRENGTH OF GEARING.

s = strain in lbs. to be transmitted, calculated at pitch circle.

p = pitch in inches.

c = constant, when teeth of ordinary proportion =

Material.	Plain.	Shrouded.
Cast steel	4000	6000
Wrought iron	3000	4500
Malleable cast iron ..	2000	3000
Gun metal	1500	2000
Cast iron..	1000	1500

$$s = p^2 c. \qquad p = \sqrt{\frac{s}{c}}.$$

For slow speeds and uniform pressure, c may be increased one-fourth.

139. JOURNALS FOR SHAFTS AND AXLES.

Length of brass = $0 \cdot 9$ to $1 \cdot 0$ length of journal.

Less liable to score in wearing, if slight end play can be given.

Thickness and projection of collar and radius of curves = $\frac{d}{8}$ to $\frac{d}{6}$.

Coefficient of friction, average $\cdot 08 = \mu$.

Work expended in friction in foot lbs. per min. =

$$\mu \, W \frac{\pi}{12} d \, R = \cdot 021 \, W \, d \, R.$$

Length of journal depends upon the load and speed, length being increased for high speeds.

$$l = \frac{W \, (50 + \text{vel. ft. per min.})}{70{,}000 \, d.} \, (\textit{Bourne}), \text{ or}$$

$$l = d \, (\cdot 004 \, R + 1) \, (\textit{Unwin}).$$

Increasing diameter increases friction, because the rubbing surface has further to travel in one revolution.

Increasing length does not affect the friction, because for a given space passed through, with a constant load, the friction is independent of surfaces in contact.

When an overhanging journal is increased in length the diameter must also be increased slightly, to give same strength as before, $D = d\sqrt[3]{\frac{L}{l}}$. Pressure on bearings per square inch longitudinal section may be $= \frac{70{,}000}{50 + v.\text{ feet min.}}$, but must never exceed 1000, maximum say 800 in engines.

140. Ordinary Proportions of Keys.

$$\text{Width of key} = \begin{cases} \frac{1}{4} \text{ diam. of shaft up to 4 inches.} \\ \frac{1}{5} \quad \text{,,} \quad \text{4 inches to 8 inches.} \\ \frac{1}{6} \quad \text{,,} \quad \text{8 inches to 12 inches.} \end{cases}$$

Key square at thick end—

One-third of thickness let in shaft, remainder in wheel.

141. Proportions of Cotters through Bars.

b = Breadth of cotter.

t = Thickness of cotter.

d = Diameter of bar.

Through round bars,

$$b = 1 \cdot 4635d. \quad t = \frac{d}{5}.$$

Through square bars,

$$b = 1 \cdot 5 \text{ side of bar.} \quad t = \frac{\text{side of bar}}{4}.$$

142. Screw-Cutting.

Set of change wheels numbers 22; increasing by 5 teeth from 20 to 120, two being alike, generally 80 or 90. When 25 in a set, the extra wheels are 130, 140, and 150.

Wheels of 10 and 15 teeth are supplied when the screw-cutting gear works the slide rest.

Leading screw has usually 2, 3, or 4 threads per inch. Double train must always be used when $\frac{\text{leading screw}}{\text{screw required}}$ is less than $\frac{1}{8}$, generally when less than $\frac{1}{4}$.

143. Screw-Cutting.

To find the wheels for any pitch.

Single train—

$$\frac{\text{Threads per inch in leading screw}}{\text{Ditto in screw to be cut}} = \frac{\text{driver}}{\text{follower}}.$$

Double train—

$$\frac{\text{Threads leading screw}}{\text{Threads screw required}} = \frac{\text{driver}}{\text{follower}} \times \frac{\text{driver}}{\text{follower}}.$$

144. Examples of Change Wheels for Screw-Cutting.

Single trains—

Leading screw, 4 threads / Required do., 7 „ $\quad \frac{4}{7} \times \frac{5}{5} = \mathbf{\frac{20}{35}}$, or $\times \frac{15}{15} = \mathbf{\frac{60}{105}}$

Leading screw, 4 threads / Required do. $2\frac{3}{4}$ „ $\quad \frac{4}{2\frac{3}{4}} = \frac{16}{11} \times \frac{10}{10} = \frac{160}{110} \div \frac{2}{2} = \mathbf{\frac{80}{55}}$

Double trains—

Leading screw, 4 threads / Required do, $\frac{5}{8}$ pitch $\quad \frac{5 \times 4}{8} = \frac{5 \times 4}{2 \times 4} = \frac{50 \times 40}{20 \times 40} = \mathbf{\frac{50 \times 80}{20 \times 80}}$

Leading screw, 4 threads / Required do., 100 „ $\quad \frac{4}{100} = \frac{2 \times 2}{5 \times 20} = \frac{20 \times 20}{50 \times 200} = \mathbf{\frac{20 \times 10}{50 \times 100}}$

Trains to be used are shown in broad-faced type.

NOTE.—Work out same with leading screw of three threads.

145. Notes on Spiral Springs.

Effective No. of coils = generally 2 less than apparent number, owing to flattening at ends for bases.

Stroke = effective number of coils × compression or extension of each coil.

Pitch of spiral = diameter of steel in inches + twice compression of one coil under full load, but coils may lie close when spring is for tension only.

Diameter of coil = say 8 times diameter of steel.

Working load may stretch each coil = ½ diameter of steel composing spring.

To increase stroke add to the number of coils.

Spring in tension is more accurate for exact work than one in compression.

Best form of section is circular, but square form is stronger, as 10 to 7.

146. Spiral Springs.

Formula for strength and deflection.

E = Compression or extension of one coil in inches.
D = Diameter of coil in inches from centre to centre.
d = Diameter or side of square of steel composing spring in $\frac{1}{16}$ths of an inch.
W = Weight applied in lbs.
c = a constant found by experiment, which may be taken as 22 for round steel and 30 for square steel.

$$E = \frac{D^3 W}{d^4 c}.$$

147. Spiral Springs, Rankine's Formula.

d = diameter of wire in inches.
c = coefficient of transverse elasticity of wire say 10,500,000 to 12,000,000 for charcoal iron wire, and steel.
r = radius to centre of wire in coil.
n = effective number of coils.
f = greatest safe shearing stress, say 30,000.
W = any load not exceeding greatest safe load.

v = corresponding extension or compression.

W' = greatest safe steady load.

v' = greatest safe steady extension or compression.

$\frac{W}{2}$ = greatest safe sudden load.

$$\frac{W}{v} = \frac{c\,d^4}{64\,n\,r^3} \qquad W' = \frac{\cdot 196\,f\,d^3}{r} \qquad v' = \frac{12 \cdot 566\,n\,f\,r^2}{c\,d}$$

Ratio $\frac{W}{v}$ should be ascertained by direct experiment.

—*Rankine's Machinery and Millwork.*

148. Differential Pulley Calculations.

$$D : \frac{D-d}{2} :: W : P \therefore P = \frac{W \times (D-d)}{2\,D}.$$

M = modulus or efficiency of machine, then $W \times M$ = actual load lifted.

By experiment—

Five cwt. differential pulley block multiplying 16 to 1, coefficient $= \cdot 4$.

30 cwt. differential pulley block multiplying 53 to 1, coefficient $= \cdot 25$.

Note.—Load will not lower by itself when M is less than $\cdot 5$.

PART IV.

THE STEAM ENGINE.

149. Horse-Power.

Actual H.P. = 33,000 foot-lbs. per minute in all calculations, but the actual work of a horse is about 22,000 foot-lbs. per minute.

Nominal H.P. low-pressure engine (pressure 7 lbs. above atmosphere)

$= d$ in inches$^2 \times \sqrt[3]{\text{stroke in feet}} \div 47.$

Nominal H.P. high-pressure engine (pressure 21 lbs. above atmosphere),
$= \text{N.H.P. low pressure engine} \times 3.$

Do. Watt's rule for condensing engines,
$= d^2 \div 28$ (22 square inches piston per N.H.P.).

Do. Watt's rule for high-pressure,
$= d^2 \div 14$ (11 square inches piston per N.H.P.).

Admiralty N.H.P. $\doteq d$ ins. $\times$ speed feet per min. $\div$ 6000.
Indicated H.P. = mean p lbs. square inch. from indicator diagram $\times$ area of piston. ($\times$ No. of pistons) $\times$ speed in feet per minute $\div$ 33,000.
Effective H.P. = actual H.P. of work done.
Nominal H.P. = is a useless commercial term, now becoming obsolete.
Boiler H.P. = cubic feet of water evaporated per hour.

150. Steam worked Expansively.

When cut off at any part of stroke as $\frac{1}{n}$;

Then its efficiency $= 1 + \text{hyp. log. } n$.

Mean pressure $= p \times \frac{1}{n} \times (1 + \text{hyp. log. } n)$.

Terminal pressure $= \frac{p}{n}$.

All pressures are measured from perfect vacuum.

Above formulæ assume theoretically perfect indicator diagrams and expansion according to Boyle and Marriott's law.

151. Crank and Piston Notes.

a = Length of connecting rod.
b = Length of crank.
x = Distance of piston, from end of stroke furthest from crank, when point of maximum leverage is reached.

x' = Distance of piston as before, when crank has made quarter revolution from dead centre.

$$x = (a + b) - \sqrt{a^2 + b^2} \qquad x' = (a + b) - \sqrt{a^2 - b^2}.$$

These values divided respectively by $2b$ will give the proportion of stroke where these points occur.

All the distances are measured from the end of stroke furthest from crank.

152. Link Motions.

Stephenson's.—Link curved, concave side towards eccentrics, shifted to vary position of motion block, block moving in direct line with slide rod, lead increasing towards mid-gear with open rods and decreasing with crossed rods.

Gooch's.—Link curved, concave side towards spindle, maintained in central position by rod swinging on a stud, motion block shifted in link by radius rod connected to valve spindle, lead constant.

Allan's.—Link straight, link and motion block moved in opposite directions by rocking shaft, lead increasing towards mid-gear with open rods, and decreasing with crossed rods.

153. Notes on Calculation of Engine Shafts.

By law of virtual velocities, mean pressure on crank pin

$$= d^2\frac{\pi}{4} \times m \times \frac{2s}{\pi s} = \frac{d^2 m}{2} = \frac{a m}{1 \cdot 57};$$

but the force being irregular, the maximum must be taken for the crank and fly wheel shaft; say full pressure on piston acting at radius of crank,

$$= \frac{d^2 \pi p}{4} \text{ at radius } \frac{s}{2}$$

Beyond the fly-wheel $\frac{d^2 m}{2}$ may be substituted for $\frac{d^2 \pi p}{4}$, as the strain will there be practically uniform.

154. Calculation of Engine Shafts.

p = maximum boiler pressure, lbs. per square inch.
m = mean pressure in cylinder " " "
s = stroke of piston in feet.
d = diameter " " inches.
a = area " " square inches.
f = factor of safety.

	Steam engine.	Hydc. eng. and stm. winches.
Wrought iron and steel ..	$\frac{1}{8}$	$\frac{1}{10}$
Cast iron	$\frac{1}{10}$	$\frac{1}{15}$

k = ultimate strength, 1-inch bar, 1 foot radius.

	Cast steel.	Mild steel.	Wrought iron.	Cast iron.
	1250	1000	750	600
c = constant or safe load = $f\,k$.				
Steam engine ..	200	175	125	60
Hydraulic engine, &c.	125	100	75	40

D = diameter of shaft in inches.

For crank shaft:

$$D = \sqrt[3]{\frac{d^2 \times \pi \times p \times s}{4 \times 2 \times f \times k}} = \sqrt[3]{\frac{d^2\,p\,s}{2 \cdot 5\,c}}.$$

And beyond fly-wheel:

$$D = \sqrt[3]{\frac{d^2 \times m \times s}{2 \times 2 \times f \times k}} = \sqrt[3]{\frac{d^2\,m\,s}{4\,c}}.$$

For 2 cylinders, let diameter $= D + \cdot 15\,D$.
For 3 cylinders " " $= D + \cdot 3\,D$.

155. Strength of Crank Pin.

p = uniformly distributed load in lbs.
l = length of journal in inches.
d = diameter of journal in inches.

f = greatest safe stress per square inch.

say, wrought iron 6000 to 9000.

steel .. .. 9000 to 13500.

cast iron .. 3000 to 4500.

$\frac{p\,l}{2}$ = greatest bending moment at fixed end of journal.

$$M = \frac{\pi}{32} d^3 = \cdot 0982\, d^3 = \text{modulus of circular sec.} = \frac{2\,I}{d}.$$

$$I = M\frac{d}{2} = \frac{\pi}{32} d^3 \times \frac{\pi}{64} d^4 = \cdot 0491\, d^4 = \text{moment of}$$

inertia of circular section.

$$p = \cdot 0982\, d^3 f \frac{2}{l} = \frac{\cdot 1964\, d^3 f}{l} = \frac{d^3 f}{5 \cdot 1\, l}.$$

$$d = \sqrt[3]{\frac{p\,l}{\cdot 1964 f}} = \sqrt[3]{\frac{5 \cdot 1\, p\,l}{f}}.$$

156. Definitions relating to Screw Propellers.

Length = $A^1\,B^1$ measured along the axis of the shaft.

Angle = P O H, which is a plane triangle when developed.

Pitch = The distance traversed on $A^1\,B^1$ for one complete revolution of A^1 P.

Slip = The difference between the theoretical forward motion, calculated from the pitch of the screw, and the actual progress of the ship.

Area = A^1 P O B, surface of blade in square feet.

Thread or *Helix* = Outer edge of blade, O P.

Diameter = Diameter of cylinder circumscribing the thread of screw. A^1 P = radius.

157. Notes on Screw Propellers.

In the common form of propeller the screw surface is generated by a line perpendicular to the axis of the shaft revolving round the shaft and progressing uniformly along it.

Screw surfaces are also generated by a line at right angles to a conical surface; in some cases the vertex of the cone points aft, and in others forward. In some the surface is

traced out by a line perpendicular to a sphere. The object in such cases being to diminish, if possible, centrifugal action of the water.

Screws of same pitch have different angles if their diameters differ. Angle reducing as diameter increases.

The screws are either right or left-handed, and may have two, three, or four blades.

158. Slip of Screw Propeller.

Slip is less when pitch is small and speed great, but more danger from heated bearings. When pitch is small, the propeller is less liable to break from a blow.

The slip is diminished, cæteris paribus, by

1. Decreasing the angle of the screw.
2. Increasing the diameter of the screw.
3. Increasing the length of the screw.

But the friction increases rapidly with the surface of the blade.

The indicated horse power varies as the square of the speed of the ship × number of revolutions of screw × pitch.

The most economical speed is when the vessel steams half as fast again as the opposing current, or half as fast again as a vessel it desires to overtake.

159. Pitch of Screw Propeller.

Ordinary propellers have the pitch uniform throughout each blade, the angle varying with the distance from the axis, originally known as Smith's propeller.

Screws of increasing pitch are sometimes used, and known as Woodcroft's propeller.

Propellers with two blades are common in large ships, but those with three or four blades are better when the draft is small or in a rough sea.

Feathering-screws have the blades pivoted so that the angle, and thereby the pitch, may be altered.

The pitch of a screw varies with the ratio of the circle described by the screw to the immersed midship section.

PART V.

BOILERS AND BOILER FITTINGS.

160. Sensible Heat.

The *Temperature* of a body is its state with regard to sensible heat.

For purposes of measurement some definite effect produced by heat must be selected, e.g. the alteration in length or volume of a substance which expands and contracts uniformly when heated or cooled.

At all ordinary temperatures the ratio of increment in volume to increment in absolute temperature is practically constant in the case of mercury, it is moreover a liquid at such temperatures, and easily measured; hence the *Mercurial Thermometer* is that most commonly used for determining the temperature of a body.

161. Comparison of Thermometers.

	No. of Degrees between Freezing and Boiling Point of Water.	Absolute Zero of Temperature.	Freezing Point of Water.	Point of maximum Density of Water.	Boiling Point of Water.
Great Britain and America: Fahrenheit = F. ..	180	−461·2	32	39·1	212
France and part of Continent: Centigrade = C. ..	100	−274	0	4	100
Germany: Réaumur = R. ..	80	−219·2	0	3·2	80

$$\therefore 9^\circ \text{ F.} = 5^\circ \text{ C.} = 4^\circ \text{ R.}$$

To convert from one scale to another,

$$F^\circ = \tfrac{9}{5}\, C^\circ + 32, \quad C^\circ = \tfrac{5}{9}\,(F^\circ - 32), \quad R^\circ = \tfrac{4}{9}\,(F^\circ - 32)$$
$$F^\circ = \tfrac{9}{4}\, R^\circ + 32, \quad C^\circ = \tfrac{5}{4}\, R^\circ, \quad R^\circ = \tfrac{4}{5}\, C^\circ.$$

162. Transfer of Heat.

Radiation of heat is the transfer which takes place between bodies at all distances apart, in the same manner and according to the same laws as the radiation of light.

Conduction is the transfer of heat between two bodies, or parts of a body, which touch each other.

Convection, or carrying of heat, means the transfer and diffusion of the state of heat in a fluid mass by means of the motion of the particles of that mass.

163. Mechanical Equivalent of Heat.

British Thermal Unit, or unit of heat, is the quantity of heat required to raise 1 lb. of pure water, at its point of maximum density ($= 39 \cdot 1°$ F.), through 1° F.

Joule's Equivalent is the mechanical effect resident in one thermal unit = 772 foot-lbs.

When the centigrade scale is used, the point of maximum density of water will be 4° C., the thermal unit the quantity of heat required to raise 1 lb. water through 1° C., and its mechanical equivalent 1390 foot-lbs.

164. Thermodynamics.

First Law of Thermodynamics—Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its disappearance, mechanical energy in the proportion of 772 foot-lbs. for each British unit of heat.

Second Law of Thermodynamics.—If the total actual heat of a homogeneous and uniformly hot substance be conceived to be divided into any number of equal parts, the effects of these parts in causing work to be performed are equal.

165. Capacity of Bodies for Heat.

Capacity for heat of a body is the number of units of heat required to raise one pound weight of the body one degree in temperature.

The *Specific heat* of a body is its capacity for heat compared with that of an equal weight of water.

Latent heat is the heat absorbed or disengaged by a body without alteration of temperature, upon a change of state or alteration in the aggregation of its molecules.

166. Latent and Sensible Heat.

Dr. Black's theory of the latent and sensible heat of steam was that the sum of the two was constant at all temperatures.

Regnault's experiments showed that the total heat was not constant, but increased slowly with increase of temperature, and was equal in F.° to

(Sensible temperature in F°. $\times$ ·305) + 1082.

167. Gases and Vapours.

Permanent gases are those which cannot be liquefied.

Ordinary gases are those which do not liquefy at ordinary temperatures or pressures, and the farther they are removed from their point of liquefaction the nearer they approach the character of permanent gases.

Vapours are gases near their point of liquefaction. Ordinary high or low pressure steam is a vapour, superheated steam is a gas.

The temperature being constant, the volume of a gas is inversely as its pressure (*Boyle's Law*).

When a gas is heated, the expansion is about $\frac{1}{273}$ of its volume at 0° C. for each ° C. increase of temperature.

168. Atmospheric Pressure.

The weight of the atmosphere at 60° Fahr. and 30 ins. barometric pressure is 14·6757 lbs. per square inch.

No. of atmos. $\times$ ·006557 = tons per square inch.

Absolute pressure is the pressure from zero, or the pressure of the atmosphere added to the indication of the pressure gauge, say gauge pressure + 15 lbs.

All questions of expansion and compression of steam must be worked from absolute pressure or perfect vacuum line of indicator diagram.

169. Properties of Saturated Steam.

Absolute Pressure.	Gauge Pressure.	Sensible Temperature.	Latent Heat.	Total Heat.	Weight of Cub. Foot.	Relative Volume.
14·7	0·0	212·0	966·1	1178·1	·0380	1642
65	50·3	298·0	906·3	1204·3	·1538	405
70	55·3	302·9	902·9	1205·8	·1648	378
75	60·3	307·5	899·7	1207·2	·1759	353
90	75·3	320·2	890·9	1211·1	·2089	298
115	100·3	338·0	878·5	1216·5	·2628	237

170. Experiments on Evaporation in Boilers.

Class.	Size.	Lbs. Water per lb. Coal.	Lbs. Coal per cub. foot Water.
Cornish	20 H.P.	6·764	9·212
Lancashire ..	25 „	7·547	8·256
Galloway ..	35 „	9·5	6·579
Field	..	10·9	5·734

171. Evaporative Value at Different Temperatures.

In stating the evaporative power of a boiler it is usual to express it in terms of feed-water evaporated from 212°.

t = actual temperature of feed-water.

T = total heat of steam under given pressure.

c = cubic foot of water evaporated from $t°$.

C = „ „ „ from 212° by same quantity of heat.

T—t = heat imparted.

$$C = c\,\frac{T - t}{966 \cdot 1}.$$

172. Loss of Heat in Boilers.

Assuming that it requires 10 lbs. of coal to evaporate 1 cubic foot of water from 60° into steam at 60 lbs. per square inch gauge pressure, the loss of heat may be shown, as follows, to be about 50 per cent:—

Total heat of combustion in 1 lb. of coal in British thermal units = 14,700.		
14,700 units per lb. × 10 lbs. coal	=	147,000
Steam at 60 lbs. pressure has a total heat of 1207 units, 1207 − 60° temp. of feed-water = 1147 units per lb. of water.		
1 cub. foot water = 62·5 lbs. 62·5 × 1147	=	71,687
Loss in chimney, 24 lbs. air, required to burn 1 lb. coal. 24 × 10 = 240 lbs. to burn 10 lbs. coal. Specific heat of air = ·2374, temperature of escaping gases = 600°.		
240 × ·2374 × 600	=	34,185
Loss in hot ashes, fuel dropped through, &c., say 10 per cent. of total heat	=	14,700
Loss by radiation and conduction, say 10 per cent.	=	14,700
Loss by imperfect combustion, say 7½ per cent.	=	11,025
		146,297

173. Heat in Boiler Furnaces.

(1) Temperature of furnace, say about 2500 °F.
(2) „ of escaping gases, say 600 to 1200 °F.
(3) „ steam and water in boiler, say 300 °F.
(4) „ water in condenser, say 100 °F.

Difference between (1) and (2) is absorbed by the water in raising its temperature, by the steam as latent heat, and by the air entering furnace in excess of quantity required for combustion.

Difference between (2) and (3) is utilised in creating draught; 600° is the most economical temperature of escaping gases as it allows sufficient difference of temperature for rapid passage of heat to water, and the density is sufficiently reduced to give rapid ascending current in chimney shaft.

Difference between (3) and (4) is utilised in the engine.

The difference of temperature or quantity of sensible heat does not by itself represent the comparative efficiency. See article 172.

174. Coal burnt per square foot of Fire-grate.

	lbs. per hour.
Cornish boilers for pumping engines ..	4 to 10
„ and others for factory uses ..	10 „ 15
Marine boilers, ordinary rates	15 „ 20
Boilers with strong chimney draught ..	20 „ 30
Locomotives	60 „ 120

175. Combustion of Fuel.

Two to three lbs. oxygen = 120 to 180 cubic feet of air, required to burn 1 lb. of coal, or, assuming only $\frac{2}{3}$rds effective, 180 to 270 cubic feet will be required.

Air and smoke together equal about 2000 cubic feet per cubic foot water evaporated, temperature say 800° Fahr.

Area of fire-grate = 1 square foot per N.H.P.

„ heating surface = 1 square yard per N.H.P.

Cubic feet evaporated per hour = N.H.P. of boiler.

Steam space of boiler = quantity required for one revolution of engine × 10.

Water space = 5 to 10 cubic feet per N.H.P.

Area of chimney in square inches =

$$\frac{2 \times 112 \times \text{N.H.P. or cubic foot per hour}}{\sqrt{\text{Height}}}.$$

176. Horse-Power of Boilers.

S = heating surface in square yards.
g = grate surface in square feet.

$$H.P = c\,(S + g)$$

$c = 1$ for ordinary coal.
$\frac{3}{4}$,, good steam coal.
$\frac{1}{2}$,, best coal only.

—*R. Armstrong.*

a = area in sq. ft. of water surface in boiler + horizontal sectional area of furnace tube in Cornish or Lancashire boiler.

	H.P. =			
Plain cylindrical boiler	$\frac{a}{6}$	..	..	$\sqrt{Sg}$
Cornish or Lancashire boiler ..	$\frac{a}{6 \text{ to } 8}$	..	$\frac{3}{5}$ S	
Galloway boiler	$\frac{a}{4{\cdot}5}$	..	..	
Multitubular boiler	..	$\frac{g}{{\cdot}5 \text{ to } {\cdot}8}$	$\frac{1}{2}$ to $\frac{1}{3}$ S	$1{\cdot}8\sqrt{Sg}$
Marine boiler (I.H.P. = 5 N.H.P.	..	..	..	${\cdot}7\sqrt{Sg}$

The average number of cubic feet water evaporated per hour from cold feed with ordinary firing and good steam coal, is generally taken as the nominal H.P. of boiler, but half a cubic foot is sufficient to develop 1 indicated H.P. in most steam-engines.

177. Boiler Furnaces.

With bituminous fuel the layer in the furnace should be about 6 inches thick, and should never exceed 12 inches.

Thin firing is more economical, but requires more careful stoking. Fresh fuel should be put in front of the fire and the red-hot fuel pushed back, or should be spread thinly over the surface after the hollows are filled up. With coke or hard coal the fire may be thicker, especially if a blast be used.

178. Heating Surface of Boilers.

Class.	Proportion of Heating Surface to Grate Surface.	Heating Surface to Evaporation, 1 cubic foot per hour.
		square feet
Plain cylindrical	10–16 to 1	18
Cornish and Lancashire ..	15–25 to 1	14
Multitubular	30–40 to 1	9
Locomotive	60–80 to 1	6

179. Comparative Value of Heating Surfaces.

Area of shell exposed to flame = 1.
Horizontal area above flame = 1.
Surface inclined towards flame = 1.
Vertical surface = $\frac{1}{2}$.
Surface inclined from flame = 0.
Horizontal surface below flame = 0.
Internal cylindrical flues = $\frac{1}{2}$ circumference.
Small tubes = $\frac{2}{3}$ „

180. Fire-Bars

Should not exceed 3 feet in length. Ordinary furnaces should not exceed 6 feet in length, the bars in two lengths. Dead-plate should be 9 to 15 inches wide. Fire-bars say 3 feet long, 3 inches deep in middle, $\frac{3}{4}$ inch thick at top, tapered to $\frac{3}{8}$ inch thick at bottom; bevelled one end to rest on dead-plate, to allow for expansion, and notched at other to rest on wrought iron bearer: if notched both ends there should be not less than 1-inch play. Chipping faces or dis-

tance pieces on bars should be made at both ends and middle. Air spaces between bars $\frac{3}{8}$ inch to $\frac{5}{8}$ inch, usually $\frac{1}{2}$ inch. The fire-grate should incline downwards towards the back, $\frac{1}{2}$ inch to $\frac{3}{4}$ inch per foot. Passage above bridge = one-sixth area of grate. Perforations in furnace door $\frac{3}{8}$ inch to $\frac{1}{2}$ inch diameter, total area from 2 to 5 square inches per square foot fire-grate.

181. Boiler Tubes.

Class of Boiler.	Ratio, Length to Diameter.	Ratio, Tube Area to Grate Area.
Multitubular boilers, with chimney draught	24 to 1	1 to 7
Locomotive boilers	120 to 1	1 to 4
Small marine boilers, with high-pressure engines	33 to 1	1 to 6
Large marine boilers, with condensing engines	20 to 1	1 to 3

1 square foot of fire-box is equal to 3 square feet tube surface: $\frac{1}{2}$ diameter should be left between the tubes for circulation and escape of steam.

Heating surface of small tubes = $\frac{2}{3}$ of circumference, of furnace tubes = $\frac{1}{2}$ circumference.

182. Taper of Plugs for Boiler-cocks.

For pressures up to 30 lbs. per square inch, a taper of 1 in 8 on each side is found to work well, but for pressures of about 100 lbs. a taper of 1 in 12 is necessary to insure tightness. Say 1 in 10 minimum for pressure of 60 lbs.

183. Boiler Seatings.

With old form of wheel draft the boiler was set on a mid-feather: this is the worst possible arrangement. Should be set on fireclay blocks forming side walls, the resting surfaces not wider than $\frac{1}{20}$th diameter of boiler.

Flues should be large enough for a man to pass entirely round, area should be kept as uniform as possible, corners rounded, and angles filled up.

Externally fired boilers are frequently set with flash flues, i. e. the gases pass directly from furnace, over the bridge, and along bottom of boiler, to chimney. Boilers should be set with a fall of about 1 in 200 or $\frac{1}{16}$ inch per foot towards front.

184. Size of Factory Chimney for Boilers.

W = weight of coal burnt in lbs. per hour.
A = area of chimney in square feet at top.
H = height of chimney in feet.

$$A = \frac{W}{14\sqrt{H}} \qquad W = 14\,A\sqrt{H} \qquad H = \left(\frac{W}{14\,A}\right)^2$$

Chimney for single boiler, area $= \frac{1}{8}$ fire-grate.
Do. under 150 feet high for more than one } „ $= \frac{1}{10}$ „
Do. over 150 feet high do. „ $= \frac{1}{16}$ „

$$\text{Area of chimney in square inches} = \frac{\text{lbs. coal per hour} \times 12}{\sqrt{\text{height feet}}}.$$

—*Bourne.*

Area of chimney usually $\frac{1}{10}$ area of fire-grate and 40 feet high.—*Scott Russell.*

20 square inches area per N.H.P. of engine.
Height about 20 times internal diameter.
Flues $\frac{1}{8}$ area of fire-grate, diminishing to $\frac{1}{10}$ at chimney.
Height of chimney = 45 feet.

$$\text{Area of chimney} = \frac{\text{area fire-grate}}{\sqrt{\text{height}} \times 1\cdot 58}$$ —*Elswick.*

Ordinary velocity of gases in chimney shaft $= 2\cdot 4\sqrt{H}$.
Most economical temperature of escaping gases = 600° Fahr.

At this temperature the volume of air entering furnace is doubled on exit.

A cubic foot of water requires 10 lbs. coal to evaporate it; 10 lbs. coal require 210 lbs. air for complete combustion, = say 2750 cubic feet.

185. Brick Chimney-shafts.

The bond usually adopted is 1 course of headers to 4 of stretchers.

Up to 120 feet high the top length is generally one brick thick; above that height, top length $1\frac{1}{2}$ brick thick.

Height of any length of uniform section should not exceed 90 feet, and should be less in thin sections.

Outside diameter at ground line should not be less than $\frac{1}{10}$th the height.

45 feet is an ordinary height for two steam boilers, but in some towns, as Manchester and Leeds, the minimum height allowed is 90 feet.

186. Sea-water.

Proportion of salt in water of open sea, 32 to 38 parts per 1000; Red Sea 43, Baltic 6·6, Black Sea 21, Arctic Ocean 28·5 British Channel 35·5, Mediterranean 38.—*Ure.*

Average specific gravity of sea-water 1·027, pure distilled water being 1. Salts contained per 1000: Chloride of Sodium 25 parts, Muriate of magnesia 3, Sulphate of magnesia 2, Sulphate of lime 1, others 1,—total 32.—*Faraday.*

Weight of one cubic foot, about 64·14 lbs.

187. Boiler Incrustation.

Order of deposition of impurities as water becomes concentrated:

1. Carbonate of lime.
2. Sulphate of lime.

3. Salts of iron, as bases or oxides, and some of these of magnesia.

4. The silica or alumina, usually with more or less of organic matter.

5. Common salt.—*M. Cousté.*

188. To Calculate Size of Boiler.

Say Cornish boiler for high-pressure engine:

d = diameter of cylinder in inches.
s = stroke in inches.
R = revolutions per minute.
r = ratio of cut-off.
p = boiler pressure, lbs. per square inch by gauge.
n = number of cylinders.
S = cubic feet steam required per hour, allowing 25 per cent. for contingencies.

$$S = 1 \cdot 25\, d^2 \frac{\pi}{4}\, s\, r\, 2\, n\, R\, 60 = \text{say } 120\, d^2\, s\, r\, n\, R.$$

v = relative volume of steam at p pressure.
W = weight of water to be evaporated in lbs. per hour.

$$W = \frac{62 \cdot 5\, S}{v}.$$

c = combustion of coal in lbs. per square foot fire-grate per hour, say for Cornish boiler = 12 lbs.
e = evaporation in lbs. of water from 60° Fahr. per lb. of coal, say for Cornish boiler = 7 lbs.
$c \times e$ = lbs. water evaporated per square foot fire-grate per hour.
A = area of fire-grate in square feet.

$$A = \frac{W}{c\, e}.$$

l = length of fire-grate in feet, say 4·5 to 5·5.
w = width " " "

$$w = \frac{A}{l} + \cdot 166.$$

D = diameter of boiler shell = $2\,w$.
L = length of „ = $4\,D$.

When w exceeds $3 \cdot 25$, make two Cornish boilers or one Lancashire.

For latter, $D = 2\frac{1}{2}\,w$ (w being width of *one* furnace).

189. To Calculate Safety-valve Leverage.

a = area of valve in square inches.
p = gauge pressure in lbs. per square inch.
W = weight on end of lever in lbs.
w = weight of lever in lbs.
w' = weight of valve in lbs.
L = distance between weight and fulcrum in inches.
g = do. centre of gravity of lever and do.
l = do. valve centre and do.

$$W = \left(p\,a - w' + \frac{w\,g}{l}\right)\frac{l}{L}. \qquad L = \left(p\,a - w' + \frac{w\,g}{l}\right)\frac{l}{w}.$$

$$p = \frac{\dfrac{w\,g + W\,L}{l} + w'}{a}. \qquad a = \frac{\dfrac{w\,g + W\,L}{l} + w'}{p}.$$

190. Ultimate Strength of Boiler-shell.

Longitudinal strength:

$$p\,d\,l = 2\,t\,l\,c \therefore p\,d = 2\,t\,c.$$

$$p = \frac{2\,t\,c}{d} \qquad t = \frac{p\,d}{2\,c}$$

Transverse strength:

$$p\,\frac{d^2\pi}{4} = \pi\,(t + d)\,t\,c.$$

divide by $\frac{\pi}{d}$, then

$$p\,\frac{d}{4} = \left(\frac{t}{d} + 1\right)t\,c;$$

but $\frac{t}{d}$ will rarely exceed ·01, and may therefore be omitted.

$$\therefore p\,\frac{d}{4} = t\,c, \quad p = \frac{4\,t\,c}{d}, \quad t = \frac{p\,d}{4\,c},$$

or the transverse strength is double the longitudinal.

191. Collapsing Pressure of Boiler-tubes.

Length not exceeding 15 diameters.

Cylindrical:

$$p = 33 \cdot 61 \times \frac{(100\,k)^{2 \cdot 19}}{L\,d} \qquad \text{—*Fairbairn.*}$$

or $\log p = 1 \cdot 5265 + 2 \cdot 19 \log. 100\,k - \log L\,d$;
or approximately,

$$p = \frac{800{,}000\,t^2}{L\,d}.$$

Elliptical:

$$p = \frac{800{,}000\,t^2}{L\,(2\,r)}, \quad r = \text{radius of flatter curve.}$$

$$p = \frac{800{,}000\,t^2}{L} \times \frac{2\,D^2}{d}.$$ D d are the two diameters in inches.

192. Boilers—Comparison between Bursting and Collapsing Pressures.

P = internal or bursting pressure in lbs. per square inch.
p = external or collapsing „ „ „
c = ultimate strength of single rivetted joint = say 30,000 lbs.
l = length of unsupported cylindrical tube in feet.
D = diameter of boiler in inches.
d = „ tube „
T = thickness of shell plate in inches.
t = „ tube „ „

R = ratio of tube diameter to shell diameter $= \frac{d}{D}$.

$$P \frac{2\,T\,c}{D} = \frac{60{,}000\;T}{D}.$$

$$p = \frac{800{,}000\;t^2}{l\,d}.$$

$$\therefore \frac{P}{p} = \frac{60{,}000\;T\,l\,d}{800{,}000\;t^2\,D} = \frac{T\,l\,R}{13 \cdot 3\;t^2}.$$

$$\therefore \text{When } P = p, \text{ then } l = \frac{13 \cdot 3\;t^2}{R\,T}.$$

193. Factor of Safety, Steam Boilers.

Test pressure = $\frac{1}{3}$ ultimate strength.

Working pressure, if under periodical inspection, = $\frac{1}{5}$ do.

Working pressure, if not under independent inspection, = $\frac{1}{8}$ do.

194. Testing Boilers.

Government Yards.—New boilers to be tested to three times their working pressure. Boilers in use not to be worked more than 300 hours without being laid off for examination. To be tested periodically to twice their working pressure.

Best private practice.—New boilers to be tested to twice their working pressure. Boilers in use not to be worked more than 1000 hours without being laid off for examination. To be tested after repairs to $1\frac{1}{2}$ times their working pressure.

195. Duty of Engines.

s = Standard of comparison in lbs: =
Cwt. any coal .. .. 112 lbs.
Bushel Welsh coal .. 94 „
„ Newcastle coal .. 84 „
w = lbs. wt. coal burnt per I.H.P. per hour.
n = no. of cwts. or bushels burnt per hour.

$$\text{Duty in ft.-lbs. per standard} = \frac{\text{I.H.P.} \times 33{,}000 \times 60}{n}.$$

$$\text{Do.} \qquad = \frac{33{,}000 \times 60 \times s}{w}.$$

$$\text{Duty in million ft.-lbs. per cwt.} = \frac{221 \cdot 76}{w}.$$

Cornish duty:
g = gallons of water pumped per hour.
f = feet lift of water pumped.

$$\text{Duty} = \frac{10\,g\,f}{n}.$$

196. Steam Pipes.

Thickness between 2″ and 12″ diameter and up to 70 lbs. boiler pressure, cast iron,

$$d + 4 = t \text{ in } \tfrac{1}{16}\text{ths of an inch;}$$

for exhaust steam, suction, and ordinary low pressure pipes, cast iron,

$$d + 10 = t \text{ in } \tfrac{1}{32}\text{nds of an inch.}$$

PART VI.

HYDRAULIC MACHINERY.

197. Summary of Hydraulics.

The quantities discharged from different apertures of similar character vary directly as the areas, and as $\sqrt{\text{altitudes}}$.

On account of friction, a small orifice discharges proportionally less water; and of several orifices having the same area, that with the smallest perimeter discharges most: hence a circular orifice is the most advantageous.

Water issuing from a circular aperture is contracted at distance of ½ diameter from orifice, from 1 to $\left\{\begin{array}{ll}\text{Bossut} & \cdot 666 \\ \text{Venturi} & \cdot 631 \\ \text{Eytelwein} & \cdot 64\end{array}\right\}$ in area, called "vena contracta." Vein contracts more with greater head, therefore discharge slightly diminished below theoretical discharge due to altitude.

The discharge through a tube of diameter = length is the same as through simple orifice of equal diameter. The discharge increases up to a length of 4 diameters.

The discharges through horizontal conduit pipes are directly as the altitudes and inversely as $\sqrt{\text{length}}$. To have perceptible and continuous discharge, head must not be less than $\frac{\text{length}}{1300}$. Vertical bends discharge less water than horizontal, and horizontal bends less than straight pipes.

In prismatic vessels twice as much is discharged from the same orifice if the vessel be kept full, during the time it would take to empty itself.

198. Comparison of Discharge through various Apertures.

Theoretical velocity in feet per second $= \sqrt{\text{Head in ft.} \times 2\,g}$.

Theoretical discharge being 1·,
Short tube projecting into reservoir = ·5.
Orifice in thin plate, 1″ diameter = ·62.
Tube 2 diameters long = ·82.
Conical tube approaching form of contracted vein = ·92.
Do. edges rounded off = ·98.

199. Useful Numbers in connection with Water.

A standard or imperial gallon of water was formerly 277·274 cubic inches, is now 10 lbs. avoirdupois at 62° Fahr. and 30″ bar. = 277·123 cubic inches or ·160372 cubic feet.—*Capt. E. M. Shaw.*

Cubic feet per minute × 9000 = gallons per 24 hours.
Head in feet × ·434 = lbs. per square inch.
Lbs. per square inch × 2·3 = foot-head.
Tons × 224 = gallons.
Diameter inches^2 ÷ 10 = gallons per yard.

200. Discharge through Pipes from Natural Head.

	d.	c.	d.	c.
H = head of water in ft... ..	1	4·71	7	612·32
L = length of pipe in ft... ..	1¼	8·48	8	854·99
d = diam. of pipe in inches ..	1½	13·02	9	1147·61
c = constant (see Table) ..	2	26·69	10	1493·47
W = cub. ft. discharged per min.	2½	46·67	12	2356·00
	3	73·50	15	4115·93
$W = \dfrac{c}{\sqrt{\dfrac{L}{H}}}$	4	151·02	18	6493·14
	5	263·87	24	13328·0
	6	416·54	30	23282·0

—*Beardmore.*

10 to 12 feet head is absorbed in friction per mile of pipe.—*Bateman.*

201. Hydraulic Pressure Accumulator,

Invented by Sir W. G. Armstrong in 1850, consists of vertical cylinder and ram, to the crosshead of which a load of 20 to 120 tons is hung to create the pressure necessary for working the machinery, obviating the use of a high tower giving a natural head of water.

The load is usually contained in a cylindrical casing. Clean washed heavy Thames ballast weighing 27 cwt. per cubic yard is the cheapest and best procurable in London. Where convenient, railway ballast may be used. Iron slag is sometimes used: it has the advantage of weight, and therefore occupies less space, but is expensive and very awkward to handle. Copper ore slag is not suitable, owing to the

galvanic action set up. Water has been used for ballast where the pressure is required to be varied occasionally. Clay has also been used in its natural state, but is better when burnt. Iron kentledge, brickwork, cast-iron blocks and direct steam pressure have also been used by various manufacturers for producing the load.

202. Pressure in Pipe-Mains.

Working pressure averages 700 lbs. per square inch when given by Accumulator, but may be from 350 lbs. to 1000 lbs.

700 lbs. per square inch = 549·78 lbs. per circular inch, equivalent to 1613·2 feet-head.

All pipes subject to the Accumulator pressure to be tested to 2,500 lbs. per square inch before leaving the works, and to 2000 lbs. per square inch after being laid.

Water companies' pipes to be tested with a pressure equal to 500 feet-head, and while under pressure to be sounded from end to end with a 5-lb. hammer

Pressure in water companies' mains is at maximum between 2 and 3 A.M., minimum 6 A.M. to 6 P.M., variation say from 10 to 60 lbs. per square inch.

203. Variation of Accumulator Pressure due to working of Machinery.

Normal pressure, say 700 lbs. per square inch. Average variation, from 50 lbs. below to 100 lbs. above the normal pressure. Maximum variation, 250 lbs. above and below, but this only occurs on a long line of pipe where the Accumulator is at some distance from the machine.

204. Friction of Accumulators.

P = pressure in lbs. per square inch taken at half stroke, Accumulator rising slowly.

p = pressure in lbs. per square inch, Accumulator falling slowly.

f = friction of ram in lbs. per square inch.

$$f = \frac{P - p}{2}.$$

At the Marseilles Docks the friction of a 17-inch Accumulator amounted to 7·355 lbs. per square inch, or not quite 1 per cent. of the gross load.—*Hawthorn.*

At Scottish Wharf the friction of a 17-inch Accumulator was 10 lbs. per square inch.

205. Air Accumulators.

W = working capacity in cubic feet of water.
C = mean capacity for air in cubic feet.
a = cubic feet air required at atmospheric pressure to charge Accumulator.
p = mean pressure in lbs. per square inch.
P = maximum ,, ,, ,,
P′ = minimum ,, ,, ,,

$$P = \frac{p}{1 - \frac{W}{2C}} \qquad P' = \frac{p}{1 + \frac{W}{2C}}.$$

$$C = \frac{P' W}{2(p - P')} \qquad a = C\frac{p}{15}.$$

May be proportioned as follows:—

D = inside diameter in feet.
L = inside length in feet.

$$D = \sqrt[3]{\cdot 4244\, W} \qquad L = 11\, D \qquad C = 3\, W.$$

Total capacity divided thus:—

Air under maximum pressure	$= \frac{15}{22}$
Water ,, ,, ...	$= \frac{6}{22}$
Margin from level of outlet to lowest water level	$= \frac{1}{22}$

If p = 700, then P = 840 and P′ = 600.

206. Velocity of Water through Pipes and Valves.

With an Accumulator pressure of 700 lbs. per square inch, the natural velocity (theoretical) is 322·32 feet per second. It is found in practice that not more than $\frac{1}{10}$th of this can be obtained through the pipes and $\frac{1}{3}$rd through the valves, in order to maintain the proper speed of the machinery. The loss from friction in the pipes is about 1 lb. per square inch per 100 feet length, after they have been laid some time.

In order to allow for the furring-up of the small pipes, it is not safe to reckon upon more than three times the diameter of pipe in inches as the velocity obtainable in feet per second. It is also usual to calculate the velocity through the valves at not more than 98 feet per second.

207. Delivery of Water in Pipes.

v = velocity in feet per second through pipe.
a = area of pipe in square inches.
d = diameter of pipes in inches.
W = discharge in cubic feet per minute.

$$W = \frac{v\,a}{2\cdot4} \qquad v = \frac{2\cdot4\,W}{a} \qquad a = \frac{2\cdot4\,W}{v}.$$

Approximately:

$$W = \frac{v\,d^2}{3} \qquad v = \frac{3\,W}{d^2} \qquad d = \sqrt{\frac{3\,W}{v}}.$$

208. Thickness of Hydraulic Pipes.

For Accumulator pressure of 700 lbs. per square inch: Inside diameter in inches + 2 = thickness of metal in $\frac{1}{8}$ths. Filling pipes made by local firms, $\frac{1}{16}$ inch thicker.

209. Strain allowed on Wrought Iron in Hydraulic Cranes.

	Tons per square inch. Tension.	Compression.
Ballast and coaling cranes	$2\frac{1}{2}$	1
Warehouse and other cranes lifting from 1 to 5 tons	3	2
Cranes lifting more than 5 tons ..	$3\frac{1}{2}$	3

210. Effective Pressure for Hydraulic Cranes and Hoists.

p = Accumulator pressure in lbs. per square inch,
m = ratio of multiplying power.
E = effective pressure in lbs. per square inch, including all allowances for friction.

$$E = p(\cdot 84 - \cdot 02\, m).$$

211. Speed of Lifting with Hydraulic Power.

Warehouse cranes and jiggers, 6 feet per second.
Platform cranes and small luggage lifts, 4 feet per second.
Passenger and waggon hoists, 2 feet per second.
Maximum speed under any circumstances, 10 feet per second.

Warehouse cranes, other formulæ.

W = load in tons.
h = height of lift in feet.
v = velocity in feet per second.

$$v = \frac{h}{W + 10} \qquad v = 10 - 80\frac{W}{h}.$$

212. Lifting Rams for Hydraulic Cranes.

W = load to be lifted in lbs.
w = weight of ram, crosshead, sheaves, and chain.
l = height of lift in feet.

m = multiplying power.
c = coefficient of effect = $\cdot 84 - \cdot 02\,m$.
a = area of ram in square inches.
s = stroke of ram in inches.
p = Accumulator pressure in lbs. per square inch.
C = capacity of cylinder in cubic feet.

For horizontal cylinders:

$$a = \frac{W\,m}{p\,c} \qquad C = \frac{W\,l}{144\,p\,c}.$$

For vertical cylinders:

$$a = \frac{W\,m + w}{p\,c} \qquad C = \frac{W\,l + w\,s}{144\,p\,c}.$$

For inverted cylinders:

$$a = \frac{W\,m - w}{p\,c} \qquad C = \frac{W\,l - w\,s}{144\,p\,c}.$$

213. Turning Rams for Hydraulic Cranes.

W = load in tons.
R = rake in feet.
l = length between bearings in feet.
d = diameter of turning drum in feet.
p = Accumulator pressure, lbs. per square inch.
m = multiplying power of turning cylinder (usually 2 to 1).
a = area of turning ram in square inches.

Alternative formulæ:—

$$a = \frac{120\,W\,R^2\,m}{l\,d\,p} \qquad a = \frac{3000\,W\,R\,m}{l\,d\,p}.$$

$$a = \left(5906\,\frac{W\,R\,m}{l\,d\,p}\right) - 3\cdot 3.$$

214. Areas of Valves for Machinery under Accumulator Pressure.

A = area of lifting ram.
m = ratio of multiplying power.
v = velocity of load in feet per second.
V = velocity of water through valve, feet per second.
W = weight of ram, crosshead, sheaves, chain, &c. in lbs.
a = area of lifting valve (mitred spindle).
a^1 = area of lowering valve (mitred spindle).

$$a = \frac{A\,v}{m\,V} \qquad a^1 = \frac{A\,v}{m\sqrt{13 \cdot 8\,\frac{W}{A}}};$$

When cylinder is horizontal, then $\frac{W}{700}$ = area of returning ram.

215. Areas of Ports in Slide Valves.

v = velocity of load in feet per second.
m = ratio of multiplying power.
A = area of ram in square inches.

Area of pressure port $= \frac{A\,v}{98\,m}$ (opening side, V-shaped).

Area of exhaust port $= \frac{1 \cdot 5\,A\,v}{98\,m}$.

216. Diaphragm Regulator for Hydraulic Machinery.

When a hydraulic crane or hoist works too quickly, and it is desired to reduce the speed to a safe limit, it is usual to partially close the stop valve; but when there is a risk of this being interfered with, a brass diaphragm, $\frac{1}{8}$th diameter thick and about $\frac{1}{8}$ inch at edge, is placed in a pipe joint near the working valves. The hole in the diaphragm should be tapered, the small side being next to the machine. To find size:—

A = area of lifting ram, square inches.
m = ratio of multiplying power.
s = speed of lifting chain with full load foot second.
p = accumulator pressure, lbs. square inch.
a = area of small side of hole (large side = twice diameter of small side).

$$a = \frac{A\,s}{6\,m\sqrt{1\cdot932\,p - \cdot046\,m}}.$$

217. Counterweights for Crane Chains.

The overhauling weights should be oval, i. e. egg-shaped, with small end on top to avoid catching under beams, &c. Hole for chain should be $\frac{1}{8}$ inch larger than cross section of links, and interior should be cored out to $\frac{1}{4}$ inch clear all round. The approximate weight of counterbalance required is $\frac{1}{20}$th of the load.

218. Mechanical Value of Fluids under Pressure.

U = units of useful work in foot-lbs.
p = pressure in lbs. per square inch.
Q = quantity used in cubic feet.
M = modulus of machine, or coefficient of effect found by experiment, and varying with class of machine or arrangement.

$$U = 144\,p\,Q\,M.$$

219. Mechanical Value of Water under Accumulator Pressure.

Theoretically the mechanical value of water under Accr. pressure of 700 lbs. per square inch (549·78, say 550 lbs. per circular inch) is 100,800 foot-lbs., or 45 foot-tons per cubic foot of water, irrespective of the time in which it is consumed; or 3·0545 H.P. per cubic foot per minute; or 1 H.P. requires ·32738 cubic feet per minute.

Approximately this equals 1 H.P. from 2 gallons of water; but practically, allowing for all losses, about $3\frac{1}{2}$ gallons are required, or 4 cubic feet will give out 100 foot-tons in work.

220. Power required to work Hydraulic Machinery.

In hotels, wharves, &c., with several machines, allowance must be made for $\frac{2}{3}$ of the machinery working to half the full height every $1\frac{1}{2}$ minute.

$\therefore$ power per minute $= \frac{2}{9}$ total capacity of machinery.

At wharf with several cranes, $\frac{2}{3}$ machinery full lift, every $1\frac{1}{2}$ minute.

$\therefore$ power per minute $= \frac{4}{9}$ capacity of machinery.

At railway goods stations, docks, &c., where many machines are idle at one time, say $\frac{1}{8}$ machinery full height, every $1\frac{1}{2}$ minute.

$\therefore$ power $= \frac{1}{12}$ capacity of machinery.

At small wharves where cranes are rapidly worked, all machinery, full height, every $1\frac{1}{2}$ minute.

$\therefore$ power $= \frac{2}{3}$ capacity of machinery.

221. Packing for Force Pumps.

Cup-leathers may be single, double, or treble. If single, the open end should be turned towards the delivery end of the pump. If double, they may be back to back or both turned towards delivery end of pump. If treble, two should be back to back, and the third put as a duplicate to the one turned towards delivery end. In all cases the back of the leather should be closely supported by a washer curved to the shape of the leather. Double leathers back to back are generally used, and last from 2 days to 4 months, average say 1 month. Only the middle of the back of best oil-dressed hide is used.

Spun-yarn is sometimes used the same as for glands of

hydraulic machinery generally. It is plaited and formed into rings by splicing, soaked in tallow, and screwed up in a mould to form solid rings of exact size to fit pump.

Rope is sometimes used in the same way, being selected of the exact diameter required. The two latter methods are said to last from 4 to 6 months, but there is probably more leakage than with leathers.

222. Efficiency of Pumps and Accumulator.

R = any number of revolutions of engine.
r = rise of accumulator in inches for same number of revolutions.
D = diameter of accumulator ram in inches.
d = diameter of pump in inches (piston if double-acting, ram if single-acting).
s = stroke of pump in inches.
n = number of pumps.

$$\text{Efficiency} = \frac{d^2 r}{d^2 s n \text{R}}.$$

$$\left.\begin{array}{l}\text{Loss per cent of working}\\ \text{capacity of pumps} \;\; ..\end{array}\right\} = \frac{100\,\{(d^2 s n \text{R}) - (\text{D}^2 - r)\}}{d^2 s n \text{R}}.$$

When all parts are in good order, the loss in the pumps averages 5 per cent.

223. Power and Speed of Hydraulic Hauling Machines.

	Strain on Rope.	Hauling Speed, ft. per min.
Railway capstans	2000 lbs.	180
	2240 „	200
Barge „	1½ tons	120
Ship „	2½ to 5 „	80
Railway traversers ..	75 lbs. per ton of load.	
Lock gate machines ..	375 lbs. per foot width of entrance.	

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